

Dredged Material Management Options and Environmental Considerations

Edited by

Judith Pederson

E. Eric Adams

Dredged Material Management

Options and Environmental Considerations

PROCEEDINGS OF A CONFERENCE

DECEMBER 3-6, 2000

Edited by
Judith Pederson
E. Eric Adams

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Dredged Materials Management: Options and Environmental Considerations

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PREFACE

Dredging—or the process of removing sediment from the seafloor—is important for keeping harbors navigable to increasingly large ships. But the process is tricky, because it can disturb contaminants that accumulate in sediments from decades of careless disposal practices.

A three-day program including two days of conference sessions plus three parallel one-day workshops brought together 200 researchers, managers and others from around the world to discuss the management of dredged material. The workshops, led by invited speakers, focused specifically on Confined Aquatic Disposal (CAD) cells, beneficial uses of dredged material such as for wetlands creation or erosion control, and evaluation of risk assessment tools to test for sediment toxicity. The conference sessions included presentations on these topics as well as presentations on Confined Disposal Facilities (CDFs), Policy and Management, and Tools and Techniques.

We would like to express our appreciation to the following individuals and organizations who helped with the program: a) our local steering committee, including Rick Armstrong, Frank Bohlen, Deerin Babb-Brott, Barry Costa-Pierce, Scott Douglas, Tom Fredette, Deb Hadden, Carlton Hunt, Olga Quirin, Jonathan Sharp, Mike Weinstein and Steve Wolf; b) program sponsors, including Sea Grant Programs at Massachusetts Institute of Technology (MIT), New Jersey, Mississippi-Alabama, Delaware, Connecticut and Rhode Island, as well as the Massachusetts Environmental Trust; c) additional contributors to the program, including Daylor Consulting Group, The Rhode Island Marine Trades Association and the East Bay Initiative of Rhode Island; and d) Gayle Sherman, who was responsible for document layout and design.

The event was held at MIT under the auspices of the MIT Sea Grant Marine Center on Capping of Contaminated Sediments. This Center was established in 1996 as one of several MIT centers designed to conduct focused research on a particular marine subject area and to disseminate results to the marine community. This particular center was motivated by the recently completed Boston

Harbor Navigation Improvement Project (BHNIP) that relied upon capped CAD cells for disposal of dredged materials. In the project, cells were dug 10 to 20 meters below the seafloor of the Inner Harbor, filled with contaminated dredged materials and capped with a meter of clean sand from Cape Cod Canal. The clean clay dug up to create the cells was disposed of offshore. The Marine Center brought together scientists and students from MIT, the University of Massachusetts-Boston, and the Harvard School of Public Health, to study physical, chemical and biological processes, as well as associated policy issues involved with the BHNIP and similar projects. Marine Center research findings spurred modifications of BHNIP activities and stimulated additional research by others, serving as a model for adaptive management—i.e. making appropriate modifications based on new data. In addition to NOAA/Sea Grant, our center was funded by the New England Division of the Army Corps of Engineers, the US Department of Energy, the National Institute of Environmental Health Science and the US Office of Naval Research.

Judith Pederson
E. Eric Adams

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Index of Acronyms and Terms

ACOE	see USACE	ER-L	Effects Range-Low
ADV	Acoustic Doppler Velocimeter	ER-M	Effects Range-Median
AET	Apparent Effects Threshold	ESA	Endangered Species Act
AFCD	Automated Fall Cone Device	ESRF	European Synchrotron Radiation Facility
ASTM	American Society of Testing and Materials	FEPA	Food and Environment Protection Agency
ARCS	Assessment and Remediation of Contaminated Sediments	FFCP	Free Fall Cone Penetrometer
BBC	Boston Blue Clay	GAC	Granular Activated Carbon
BCF	Bioconcentration Factor	GIS	Geographic Information System
BHNIP	Boston Harbor Navigation Improvement and Berth Dredging Project	GLNPO	Great Lakes National Program Office
Big Dig	underground placement of major Boston highway	GPS	Global Position System
CAD	Confined Aquatic Disposal	GSO	University of Rhode Island's Graduate School of Oceanography
CAMD	Center for Advanced Microstructures and Devices	GUI	Graphical User Interface
CBR	Critical Body Residue	HARS	Historic Area Remediation Site
CDF	Confined Disposal Facility	HDPE	high-density polyethylene
CEFAS	Centre for Environment, Fisheries and Aquaculture Science	HPG	Horizontal Profiling Grab Bucket
CENAB	U.S. Army Corps of Engineers, Baltimore District	ICP	Inductively Coupled Plasma
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (a.k.a. Superfund program)	KYDEP	Kentucky Department of Environmental Protection
CHL	Coastal and Hydraulics Laboratory	KYDES	Kentucky Department of Environmental Safety
CMS	Crane Monitoring System	LL	Liquid Limit Values
CPT	Cone Penetrometer	LNG	Liquid Natural Gas
CSO	Combined Sewer Overflow	MADEP	Massachusetts Department of Environmental Protection
cv	coefficient of consolidation	MAFF	Ministry of Agriculture, Fisheries and Food
DDT	Dichloro-diphenyl-trichloroethane	MAS	Magic Angle Spinning
DGPS	Differential Global Position System	Massport	Massachusetts Port Authority
DO	Dissolved Oxygen	MBDS	Massachusetts Bay Disposal Site
DMCF	Dredged Material Containment Facility	MGL	GSO's Marine Geomechanics Laboratory
DTM	Digital Terrain Model	MIT	Massachusetts Institute of Technology
EIR/S	Environmental Impact Report/Statement	MLLW	Mean Lower Low Water
EPA	see USEPA	MR	Mystic River
EqP	Equilibrium Partitioning	MST	Multi-Sensor Track
ERA	Ecological Risk Assessment	MWCD	Muskingum Watershed Conservancy District
ERDC	Engineer Research and Development Center	MWRA	Massachusetts Water Resources Authority
		NAA	Neutron Activation Analysis
		NED	New England District (of USACE)

NBCDF	Newark Bay Confined Disposal Facility	TCLP	Toxicity Characterization Leaching Protocol
NMFS	National Marine Fisheries Service	TEF	Toxic Equivalency Factor
NMR	Nuclear Magnetic Resonance	TEL	Threshold Effects Levels
NOAA	National Oceanic and Atmospheric Administration	TEQ	Total Toxic Equivalence
NOEC	No Observable Effect Concentration	TIE	Toxicity Identification Evaluations
NOS	National Ocean Service	TSS	Total Suspended Solids
NRC	National Research Council	USACE	U.S. Army Corps of Engineers
NSLS	Brookhaven National Synchrotron Light Source	USEPA	U.S. Environmental Protection Agency
NTU	Nephelometric Turbidity Unit	USFDA	U.S. Food and Drug Administration
OBS	Optical Backscatter Sensor	WES	Waterways Experiment Station
O&M	Operations and Management	WQC	Water Quality Criteria
PAHs	Polycyclic Aromatic Hydrocarbons	WRDA	Water Resources Development Act
PCBs	Polychlorinated Biphenyls	WTP	Waste Water Treatment Plant
PDFT	Pre-design Field Test	XANES	X-ray Absorption Near-Edge Spectroscopy
PEL	Probable Effects Levels	XRPD	X-ray Powder Diffraction
PI	Plasticity Index	XRF	X-ray Fluorescence
POC	Particulate Organic Carbon	YSI	Yellow Springs Instruments
PSDDF	Primary Consolidation, Secondary compression and Desiccation of Dredged Fill		
psu	practical salinity unit		
RCRA	Resource Conservation and Recovery Act		
RIS&G	Ross Island Sand and Gravel		
ROD	Record of Decision		
RPD	Redox Potential Depth		
RTK	Real Time Kinematic		
SBLTs	Sequential Batch Leaching Tests		
SBT	Soil Behavior Type		
SDP	Site Development Plan		
SEM-AVS	Simultaneous Extracted Metal-Acid-Volatile Sulfides		
SGD	Submarine Groundwater Discharge		
SMS	Surface Water Modeling System		
SPI	Sediment Profile Imagery		
SPP	Suspended Particulate Phase		
SPU	Slurry Processing Unit		
SQAGs	Sediment Quality Assessment Guidelines		
SQGs	Sediment Quality Guidelines		
STFATE	Short-Term Fate of Dredged Material Disposal in Open Water		
SXM	Synchrotron X-ray Microtomography		
TAC	Technical Advisory Committee		

CHAPTER 1

Confined Aquatic Disposal Cells

Monitoring Results from the Boston Harbor Navigation Improvement Project Confined Aquatic Disposal Cells

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ABSTRACT: The dredging, filling, and capping of nine Confined Aquatic Disposal (CAD) cells for the Boston Harbor Navigation Improvement Project provided an ideal opportunity to improve construction methods and monitoring approaches for in-channel disposal. Working with the project Technical Advisory Committee and the Massachusetts regulatory agencies, it was possible to modify design requirements based on experiences gained in each successive phase of the project. In 1997, the use and monitoring of a single CAD cell lead to construction changes in cap placement for the Phase II in-channel disposal cells. Additional experience with the first three, larger Phase II cells in 1998 resulted in adoption of recommendations to increase consolidation time and minimize the use of the props on the hopper dredge during capping. These approaches were applied to the last five cells created by the project in 1999/2000 resulting in even higher levels of success than in the earlier cells. CAD cells can provide a practicable alternative for contaminated sediment management. The success and experience gained from projects such as the Boston Harbor Navigation Improvement Project will certainly increase the environmental acceptability of CAD cells as a management alternative.

Key words: CAD, capping, monitoring, Boston Harbor, MA

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Note: The findings in this paper were originally presented at the Western Dredging Association, Twentieth Dredging Seminar, June 25-28, 2000; Warwick, Rhode Island. Since the presentation at the December 2000 Technical Conference and Twenty-Second Texas A&M Conference on Dredged Material Management, a final summary report has been prepared (US Army Corps of Engineers, 2002).

INTRODUCTION

Management of silty, fine grained sediments, determined unsuitable for ocean placement, dredged from the Boston Harbor Navigation Improvement Project (BHNIP) have been placed into a series of confined aquatic disposal (CAD) cells dredged below the Federal navigation channels of the inner harbor. Following placement of these silty maintenance sediments, sand dredged from the Cape Cod Canal was used to create caps over the cells (Figure 1). Sediments from the cell construction and channel deepening were placed at the offshore Massachusetts Bay Dredged Sediment site. This unique, large-scale project has provided an excellent opportunity to improve our understanding and application of this management approach. The latest capping and monitoring, conducted at two cells in November and December 1999, have continued to support the conclusion that consolidation time is critical to cap success.

Application of the CAD management approach for the Boston Harbor project has been an evolutionary and iterative process that has been coordinated with an interagency Technical Advisory

Committee (TAC). Project progress, monitoring results, and changes in the management approaches have been continually coordinated with the TAC, consisting of local environmental interest groups, academic representatives, federal and state agencies. Involvement of these groups throughout the process enabled practical project modifications to be implemented, as needed, with each new round of cell capping and monitoring.

The creation of CAD cells for the project began in 1997 when two berths at Conley Terminal were clamshell dredged and the maintenance sediments were placed using a bottom opening barge into a small (200 x 500 ft) and relatively shallow (average of -57.5 ft MLLW) cell (Figure 2, cell IC2). Average fill elevation was -48.5 ft MLLW, resulting in about nine feet of maintenance sediments in the cell. Sand capping began nine days after placement of the maintenance sediments and continued for 12 days. Results from this first cell (referred to as the Phase I cell) demonstrated that capping was feasible, though some changes to operations were recommended. This included a recommendation to not use spudded barges for placement of cap material, because of the observed uneven distribution of sand over the maintenance sediments (Murray *et al.* 1999, Murray 1998). It was initially predicted that the sand released from the barge would flow downstream with currents within the cell. Instead, the sand cap material fell directly beneath the opening of the barge. It was also recommended that a longer consolidation time be allowed for the sediment placed in the CAD to reduce the amount of mixing between cap and maintenance sediments.

The next three cells to be dredged, filled, and capped (M4, M5, and M12) were substantially deeper (average depths of -85, -80, and -110 ft MLLW) than the Phase I cell (Fredette *et al.* 1999) (Figure 2). These cells were filled with 21, 31, and 34 feet of silt, respectively. Consolidation time between the last load of maintenance sediment and the first cap placement ranged from 30 to 52 days for these Phase II cells. Sand cap was sprinkled using a partially opened hopper dredge which maneuvered over the cells. Mixing of sand with the silt and the presence of silt layers from 1-4 feet thick on top of sand layers over portions of the cells led to the recommendation that even greater consolidation time be allowed (NB: consolidation

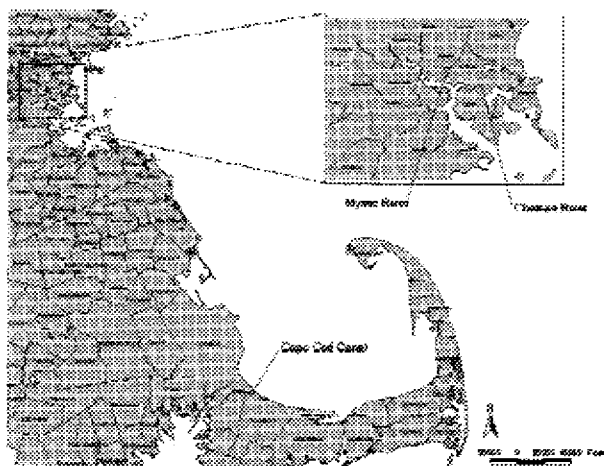


Figure 1. Location of Boston Harbor Navigation Improvement Project and Cape Cod Canal.

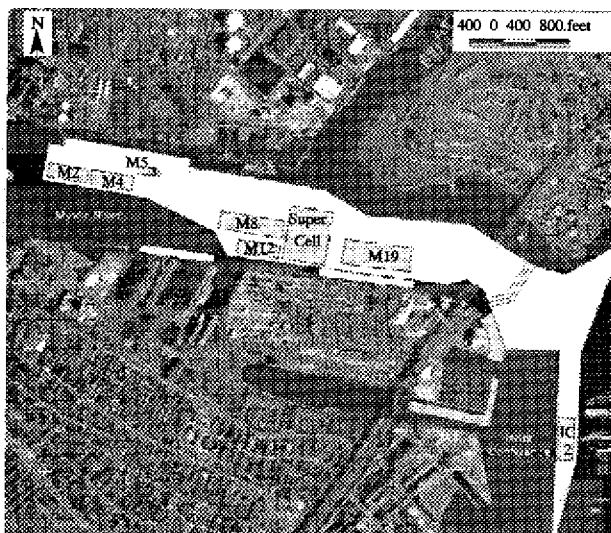


Figure 2. Boston Harbor Navigation Improvement Project, Mystic and Inner Confluence Disposal Cells.

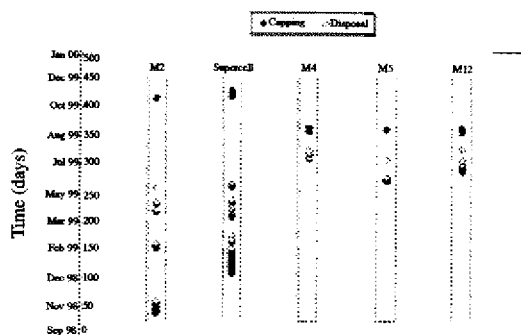


Figure 3. Time history in days of disposal, (open circle), consolidation, and capping, (closed circle), for Mystic River Cells.

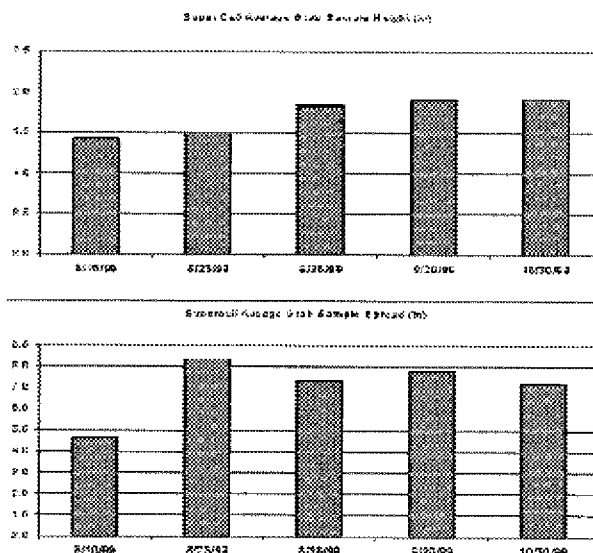


Figure 4. Supercell slump sample average height and spread.

time was initially determined by the Water Quality Certification goal of minimizing the potential short-term environmental exposure, rather than maximizing time for capping considerations). Additional changes in cap placement (discussed below) were also made to help maximize conditions for success.

Since the capping of M4, M5, and M12, five other cells have been under active use. Four of these, Supercell, M2, M8 and M19, are in the Mystic River and one, C12 (not shown), is in the Chelsea River. This paper discusses the results from the cells capped late in 1999, M2 and the Supercell. Of the remaining cells, M8 and M12 were capped in the fall of 2000 and monitoring results are currently being reviewed. As cell C12 was only partially filled, it will remain uncapped and available for future projects.

FILLING AND CAPPING OF CELL M12 AND SUPERCCELL

Cells M2 and the Supercell (so called, because of its size) had very different time histories than the prior three cells M4, M5, and M12 (Figure 3). These two cells had considerably greater consolidation times (approximately 5 months) and also had more prolonged placement of the silty maintenance sediments. Silt placement into M4, M5, and M12 took place in less than 45 days time, whereas the filling of the Supercell and M2 stretched over 6 and 8 months, respectively. Average cell depths for M2 and the Supercell were similar to the earlier Phase II cells, but the Supercell was considerably larger in footprint (Figure 2).

As part of assessing the readiness of the cells for capping, a simple slump test was used to examine changes in silt consolidation. This was done by taking three sediment grab samples periodically from each cell, placing the grab on a sheet of plywood pre-marked with concentric circles, and estimating the spread and height that the sediment maintained. Both qualitatively and quantitatively these samples provided some evidence of increased consolidation through time. The height that the material maintained showed a fairly clear trend, whereas the spread was more equivocal (Figure 4).

Capping of M2 and the Supercell used the hopper dredge, Sugar Island (Great Lakes Dredge and

Dock Company), that was opened just enough to slowly release the sand. However, for these two cells the dredge was maneuvered using a tug rather than utilizing the dredge's own engines as was done for the previous three cells. This change was made as one more means to minimize any potential for disturbance of the silt during capping. Seven hopper loads of sand (17,500 yd³) were placed over M2 and 20 over the Supercell (49,700 yd³). As for the previous three cells (Fredette et al. 1999), dredge position was recorded every ten seconds during cap placement of each load and these data were used to estimate cap coverage. Dredge position was displayed as a line representing the longitudinal axis of the dredge. This is shown for a single cap load in Figure 5 and similar data from all of the cap loads were subsequently combined to estimate cap thickness as construction proceeded.

MONITORING METHODS

Sub-bottom profiling and coring of the cells was conducted by Ocean Surveys, Inc. within two weeks of capping using the same equipment and approaches described earlier (Fredette et al. 1999). Cell M2 was surveyed on two longitudinal transects and four lateral transects (Figure 6). Surveying the larger Supercell involved four longitudinal sections and eight cross sections. Six and fifteen vibracores, respectively, were taken at intersecting points of the sub-bottom survey lanes to allow better interpretation of these two data types. Previously, it had been recommended that cores be randomly located (Fredette et al. 1999). However, additional discussion of the data from the previous cells led to the conclusion that coordination of these two data sets would strengthen the overall analysis.

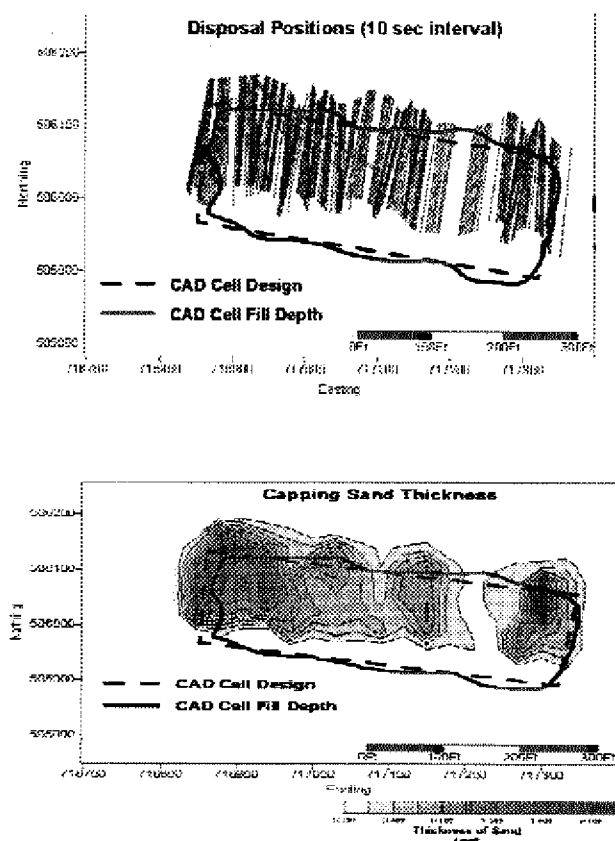


Figure 5. Position of hopper dredge during placement of load #4 into cell M2 (top) and estimated cap thickness from the single load (bottom).

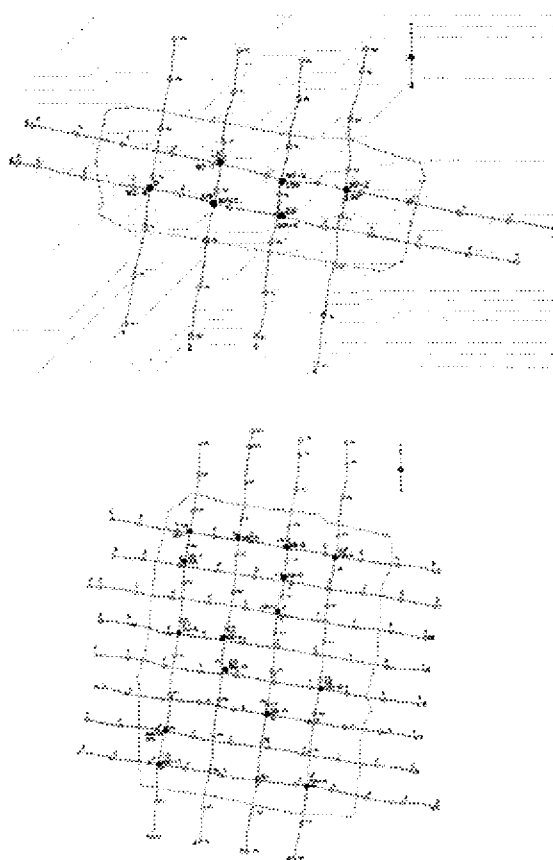


Figure 6. Sub-bottom survey lanes and core locations for cell M2 (top) and the Supercell (bottom).

RESULTS

Sub-bottom profiles of cells M2 and the Supercell showed a strong reflective layer at the surface of the cell indicative of a sand cap (Figure 7). Below the sand cap was the relatively featureless silty sediments. The sand caps showed considerable medium and large scale topographic variation and occasional internal layering, something not seen in the first three cells, because of the amount of silt mixed with the sand cap. The Supercell was also characterized by the presence of multiple diapiric structures, which appear as upward arching features in the cap (Figure 8). These diapiric structures, which are similar to those observed in geologic records, possibly were caused by movement of water or silt. These structures were almost non-existent in cell M2.

The cores provided direct physical evidence of the presence of the sand cap at the surface of the

cells (Figure 9). Most cores from the two cells showed sand from 1-4 feet thick at the sediment-water interface (5 of 6 in cell M2 and 12 of 15 in the Supercell). A few of the cores showed no sand at the surface (e.g., SS1-2, SS1-14, M2-4) and several had multiple bands of sand separated by layers of finer silty sediments (e.g., SS1-2, SS1-11, M2-5).

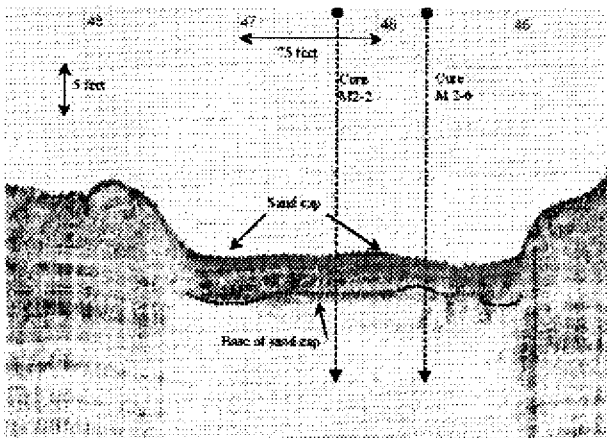


Figure 7. Sub-bottom profile line x of cell M2 showing cap and location of two cores.

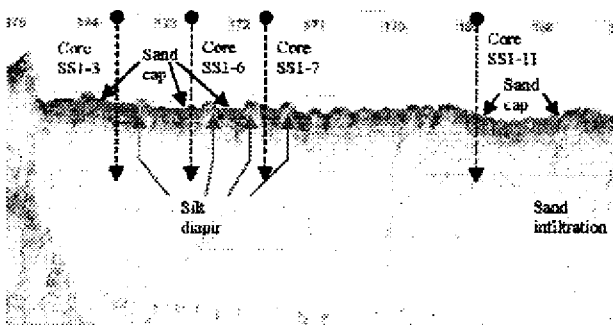


Figure 8. Sub-bottom profile along line 3 of the Supercell showing core locations and numerous silt diapirs.

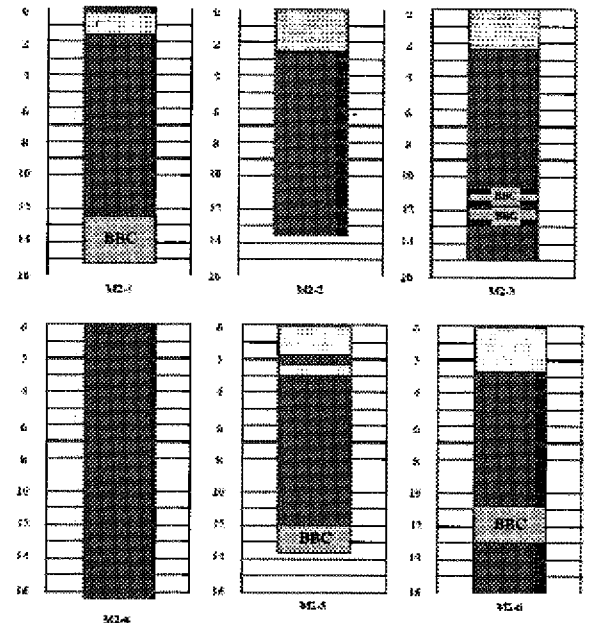


Figure 9. Core descriptions from cell M2. Sand is shown as stippled, silt as black and Boston blue clay (BBC) as gray. Units are in feet.

DISCUSSION

Both the Supercell and cell M2 appeared to have continuous sand caps ranging from one to four feet thick over the silty maintenance sediments. The M2 cap most closely matches ideal expectations, with little evidence of diapirism and more consistently thick surface sand layers in the cores. The Supercell had numerous diapiric structures, which appear as upward arching features on the sub-bottom profiles (Figure 8). Cores that showed no sand at the surface almost always appeared to be associated with the presence of one of these diapirs. For example, core SS1-2 was taken along the Supercell transect Line 2 where the presence of a diapir was clearly evident (Figure 10). Creation of these diapiric features may be caused by silts trying to move through the cap or

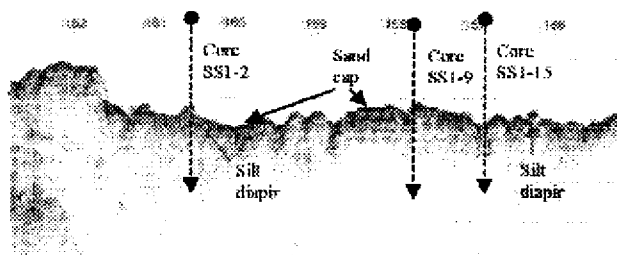


Figure 10. Sub-bottom profile along line 2 of the Supercell showing core locations and presence of silt diapirs.

just by release of water as it continues to exit from the consolidating maintenance silt sediment below. The latter explanation may be more reasonable, as there was very little evidence in the cores or sub-bottom profiles that silt had spread across the top of the sand.

The greater abundance of these features in the Supercell is very possibly related to its larger size. In all cells, the cell walls may provide channels in which consolidation water can be released, but in a larger cell the greater distance to a cell wall and the smaller ratio of cell wall to cell volume means that more water must exit through the surface. In addition, cell M2 had much of its filling occur 2 months earlier than the initial Supercell filling and M2 also had two prolonged periods of inactivity (Figure 3) where substantial consolidation could have taken place. All of these factors combined probably resulted in the Supercell being at a lower consolidation state at the time of capping even though the time from the last barge placement to capping was the same.

The longer consolidation time that was allowed for these latest two cells relative to the earlier cells appears to have had a considerable effect on the ability of the silt sediments to support the sand cap (Figure 11). Cell M2, in particular, provides almost a textbook illustration of expectations. Whereas sand in the earlier cells (especially cells M4 and M5) occurred in continuous bands across the cells, it was overlain by fluidized mud that may have oozed through diapiric vents (Fredette et al. 1999). However, the observation of some sand layers deeper in the Supercell cores and the fact that estimated sand thickness should have been a minimum of 2 ft thick, suggests that silt strength in this cell was still not sufficient to support all of the sand that was placed. It appears that the Supercell, at

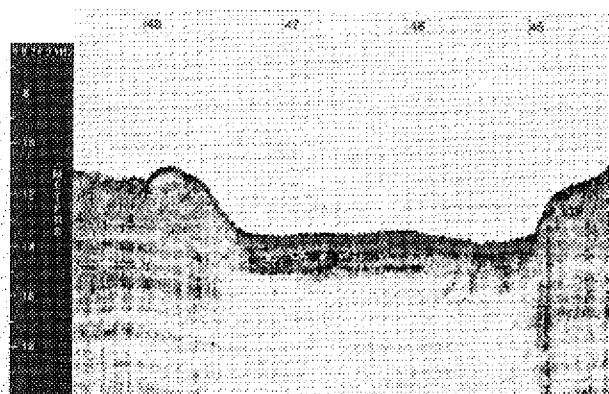
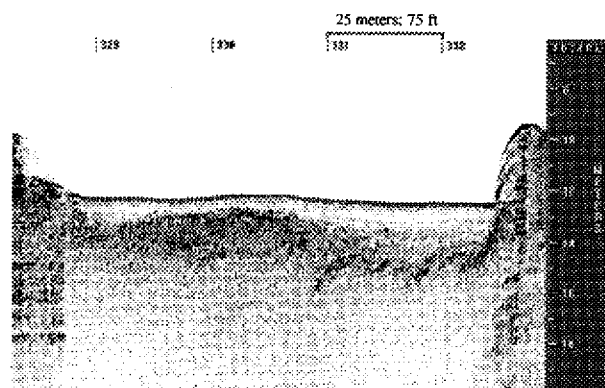


Figure 11. Comparison of survey line 40, cell M5, December 1998 (top) to line 3, cell M2, November 1999 (below).

least, may have benefited from even longer consolidation time.

Before we refine our recommendations for capping of CAD cells, some discussion of the advantages and disadvantages of capping such cells should be considered. Certainly the placement of a sand cap will help to minimize the re-introduction of the contaminated silts back into Boston Harbor and it was instrumental in gaining regulatory approval for the project. However, because of the probable depositional nature of these cells (they are below the elevation of a navigation channel which itself was depositional and in need of periodic maintenance), the sand cap itself will soon be buried with sediments very similar in nature to those it is intended to cover. Thus, the sand cap may only provide a very short-term net isolation benefit. This is also true of the potential habitat enhancements that the cap may have been envisioned to provide.

The placement of a cap into the CAD cell also

has a negative value with respect to cell capacity. Without the cap the cell can accommodate an even greater volume or the cell capacity used by a cap can simply be left to accumulate future deposition. This behavior as a sediment trap could have a long-term benefit with respect to decreasing the volume or frequency of future channel maintenance. This would both decrease the regulatory challenges of future maintenance needs and also lessen the environmental disturbance that occurs with dredging.

There are also other concerns that factor into the use of CADs and their capping, including the potential to create anoxic sinks and the impacts of large vessels on erosion of cell contents. Both of these have been considered in Boston and relevant investigations have been conducted. Sampling conducted in 1999 did not observe lower dissolved oxygen in the Boston CAD cells (Normandeau Associates, Inc. 2000), but this is an issue that may need further investigation to reach any long-term definitive conclusion. Anoxia development may also be a very locale-specific issue for which some verification monitoring may be appropriate.

An investigation was performed in the spring of 2000 to provide an initial evaluation of the effect of vessel passage over capped and uncapped cells (SAIC, 2000). Currents and suspended solids were monitored in the water column over the cells following passage of a large vessel. The monitoring revealed that bottom sediments were temporarily resuspended with the passage of the vessel, but the amount of sediment resuspended was very small. It needs to be recognized that the same sediments that are cause for concern in the CAD cell may be the same sediments that were even closer to prop wash disturbance when they were in the channel in a shallower situation.

RECOMMENDATIONS

Confined Aquatic Disposal (CAD) cells offer a practical and effective alternative for the management of contaminated sediments. However, there are several questions that need to be considered before their selection for project use. One of the most critical, for design purposes, is the necessity for a cap. If the benefits of a cap are determined to be less than the disadvantages, then consideration

of consolidation time and choice of dredging equipment take on less importance. Disadvantages of a cap include the loss of cell capacity that the cap uses and the cost associated with supplying cap, while the advantages may include isolation where rapid sediment accumulation over the cap is not anticipated.

If the use of a cap is determined necessary, then using approaches that maximize the strength of the underlying sediments becomes a large consideration. This includes the method used to dredge the sediments and the length of time that consolidation will be allowed prior to capping. Also to be considered is the choice of cap material and the method used to place the cap. If erosion of the material in the CAD is of concern then a coarse cap may be required. Sand, because of its greater density, however, may not be the best choice for a cap over silty, high water content sediments. Slurry placement of a fine grained, clean silty sediment could eliminate the need to allow consolidation and also lessen concerns about impacts of dredge selection on sediment strength. The relative density and strength differences between a maintenance silt and a silty cap would likely result in very little mixing and effective capping. Though, as learned several years ago in the New Bedford Harbor pilot project, mixing of such similar materials can occur if the cap is discharged with too much energy directly near the CAD fill elevation (US Army Corps of Engineers 1990). Even gradual disposal from a barge of similar high water content silt sediments may lessen the need for consolidation.

The Boston Harbor CAD cells represent the most extensive use of this alternative in the United States and internationally it is probably second only to their use in Hong Kong (Whiteside et al. 1996). However, the monitoring that has been conducted on the Boston cells is likely more extensive than that conducted elsewhere. With the growing consideration of the use of CAD cells throughout the world we offer the following suggestions:

- Evaluate whether a cap is necessary and advantageous. Its benefits may be short-term at best because of rapid new sedimentation.
- Maximize the strength of the fill sediments by dredging them as close to in-situ density as possible. This may include avoiding the use of hydraulic dredges or water-tight clamshell

buckets which may introduce excess water into the sediment.

- Bathymetric surveying is of limited use in assessing cap thickness, because of the ongoing elevation changes that occur due to consolidation of the sediments.
- Coring, combined with sub-bottom profiling, can be an effective means of monitoring cap success. Together these methods were very complementary, whereas alone they would have been much more difficult to interpret.
- Placement of core locations at intersecting points of the sub-bottom survey lanes proved of much greater use than randomly selected locations.
- Use of gradual cap placement and a tug to maneuver the hopper dredge are both potential means to help minimize mixing of cap and the contaminated sediments.
- Disposal of the silty material into the CAD cells from hopper or split hull barges can be accomplished successfully with little impact to water quality.
- Consolidation times of 5-6 months or longer may be needed for cells of similar dimensions and using similar fill and cap materials as in Boston. However, the length of time to fill the cell should also be considered. If filling occurs quickly, longer consolidation times of up to a year prior to capping may be reasonable.

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Dynamics of Particle Clouds Related to Open-Water Sediment Disposal

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ABSTRACT: Open-water disposal and capping are promising solutions for disposal of the 14 to 28 million cubic meters of contaminated sediment dredged annually in the United States. However, such practices raise concerns about the feasibility of accurately placing the material in a targeted area and the loss of material to the environment during disposal.

To investigate the question of sediment loss during disposal, laboratory experiments were conducted in a deep glass-walled tank using a quick-opening sediment release mechanism and a specially-designed curtain shade serving as a "sediment trap". Both non-cohesive and cohesive sediments were utilized under a variety of release conditions (varying initial momentum, water content, initial stirring, etc.). Data consisted of digital images of particle clouds illuminated by laser-induced fluorescence, and measurement of sediment mass captured on the trap at various stages of cloud descent. The major cause for particle loss was observed to be failure of material to be incorporated into the plume, rather than any observed "stripping" mechanism.

Current particle cloud models employ thermal theory and an integral approach using constant entrainment (α), drag (C_d) and added mass (k) coefficients. Our aim was to investigate how real sediment characteristics (particle size, water content and initial momentum) affect cloud behavior and hence time variations in α , C_d , and k .

Key words: particle dispersal, open-water disposal, cloud behavior

INTRODUCTION

Open-water disposal, with or without capping, is a promising solution for disposing of the 14-28 million m³ of contaminated sediment dredged annually in the United States (NRC, 1997). However, such disposal raises concerns about the ability to accurately place sediments (either contaminated dredged material or clean capping material) in a targeted area, as well as the loss of sediments to the environment during disposal.

Instantaneously released sediments form axisymmetric "clouds" resembling self-similar thermals. Current particle cloud models such as STFATE (Johnson and Fong, 1995) date back to Koh and Chang (1973). Most models employ

thermal theory with an integral approach using constant entrainment (spreading rate) (α), drag (C_d) and added mass (k) coefficients. Our aim was to see how real sediment characteristics (particle size, water content and initial momentum) affect cloud behavior and hence time variations in α , C_d and k , especially in the initial phases of plume descent of particular relevance to shallow water sites (see Figure 1). We were also concerned with the process of cloud formation, and with measuring how much of the material is initially incorporated into the cloud, as well as how much is lost during convective descent.

EXPERIMENTS

Flow visualization experiments were conducted by releasing 40 g (dry wt.) of either non-cohesive

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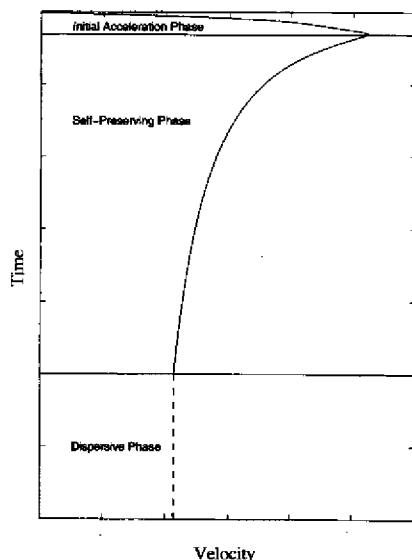


Figure 1. Phases in the convective descent of an idealized particle cloud.

glass beads, or cohesive ground silica silt (less than 36% solids by wt.). Experiments were conducted in an 8-ft-deep glass-walled tank, using a quick-opening sediment release mechanism and a window-shade type “trap” mechanism (Ruggaber, 2000). Observations were recorded using a CCD camera and framegrabber image system for subsequent image processing.

Cloud momentum was varied by changing the height-diameter ratio of the release cylinder, the cylinder’s distance above the water surface, and the amount of excess water. Conditions for three groups of experiments are illustrated in Table 1. Particle sizes were scaled to real-world dimensions (Table 2) through the cloud number (N_c) defined as the ratio of the particle settling velocity w_s to the characteristic cloud velocity,

$$N_c = w_s r / (B/\rho)^{1/2}$$

where B , r and ρ are cloud buoyancy, radius and density (Rahimpour and Wilkinson, 1992).

ANALYSIS

A simple integral-type model was employed to determine the ability of this class of model to simulate cloud behavior within the initial acceleration and deceleration phases. The model solves the

mass, momentum, and buoyancy conservation equations for a cloud of constant shape using either constant or time-varying values for α , C_d , and k . An “inverse” integral model was also developed in which the conservation equations were solved for two of the three input parameters (e.g., α and k) based on measured time variation in cloud velocity (w) and equivalent radius (r). Based on the inverse model results, particle cloud experiments were simulated with an integral model using constant and time-varying α , C_d , and k .

RESULTS FOR MODEL PARAMETERS

Table 3 summarizes results for cloud growth for the experiments described in Table 1. Non-cohesive sediments rapidly formed “turbulent thermals” with asymptotic deceleration ($w \sim t^{-1/2}$; Figure 2) and large initial growth rates ($0.2 < \alpha_1 < 0.3$). The particles eventually evolved into “circulating thermals” with linear growth rate predicted by buoyant vortex ring theory ($\alpha_2 \sim B/K^2$) where K is the cloud circulation (Ruggaber, 2000). This transition was observed when the cloud radius had approximately doubled relative to its initial submerged radius or quadrupled relative to its pre-release radius. This follows boundary layer theory and corresponds to field water depths of order 100 m. In the “circulating thermal” phase, large particles ($N_c > 10^{-4}$) produced laminar-like vortex rings with significantly slower spreading ($0.1 < \alpha_2 < 0.2$), while the smaller particles maintained close to their original values (Figure 3). Changes in water content and initial momentum produced more variation in the spreading of cohesive particles as compared with non-cohesive particles.

Inverse integral modeling suggests that C_d and k are near zero within the “turbulent thermal” phase. In the “circulating thermal” phase, the reduction in α caused by the large particles ($N_c > 10^{-4}$) increased k to a value similar to that of a solid sphere (~ 0.5). Integral model results confirm the suitability of using constant coefficients for modeling particle clouds with $N_c < 10^{-4}$, while for $N_c > 10^{-4}$, time-varying α and k are required to properly simulate cloud behavior in the “circulating thermal” regime.

Table 1. Conditions for three groups of experiments. Bold entries are varied within each group.

Experiment	Part. dia. (mm)	Part. set. vel. (cm/s)	Cyl. dia. (cm)	Cyl. ht./dia. ratio	Excess H ₂ O (cm ³)	Rel. pos.
Group I Experiments						
3.18 cm cyl., dry	0.264	3.2	3.18	1.1	0	AW
3.18 cm cyl., wet	0.264	3.2	3.18	1.3	17	AW
4.45 cm cyl., dry	0.264	3.2	4.45	0.4	0	AW
4.45 cm cyl., wet	0.264	3.2	4.45	0.5	17	AW
Group II Experiments						
40 cm ³ H ₂ O, Sus., AW	0.264	3.2	4.45	0.8	40	AW
40 cm ³ H ₂ O, Sus., BW	0.264	3.2	4.45	0.8	40	BW
40 cm ³ H ₂ O, Sus., AW	0.264	3.2	4.45	0.8	40	AW
17 cm ³ H ₂ O, Sus., AW	0.264	3.2	4.45	0.5	17	AW
Group III Experiments						
0.024 mm beads, AW	0.024	0.047	4.45	0.8	40	AW
0.024 mm beads, BW	0.024	0.047	4.45	0.8	40	BW
0.010 mm beads, AW	0.010	0.0091	4.45	0.8	40	AW
0.010 mm beads, BW	0.010	0.0091	4.45	0.8	40	BW

 Table 2. N_c scaling of particle cloud grain sizes between 27 cm³ laboratory volume and barge volumes of 10, 100, 1000 and 5000 m³.

Laboratory Dia. (mm)	Real-world diameter (mm)			
	10 m ³	100 m ³	1000 m ³	5000 m ³
0.01	0.027	0.033	0.040	0.045
0.05	0.172	0.221	0.290	0.353
0.10	0.418	0.572	0.807	1.05
0.50	5.97	13.0	33.3	64.8
1.00	33.0	83.3	165	258

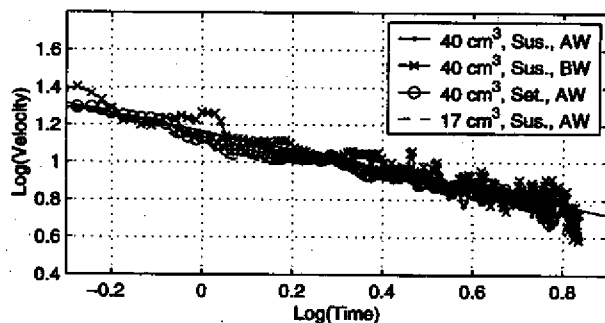


Figure 2. Cloud velocity vs. time for Group II Experiments. The -0.5 slope matches thermal theory.

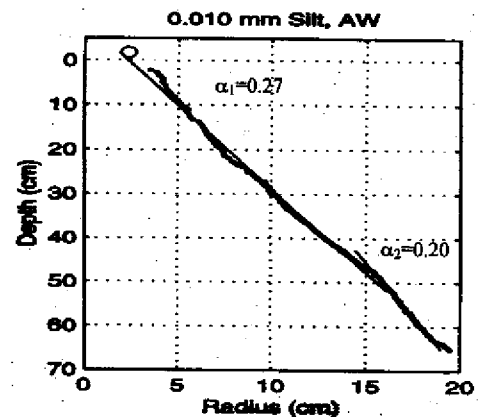
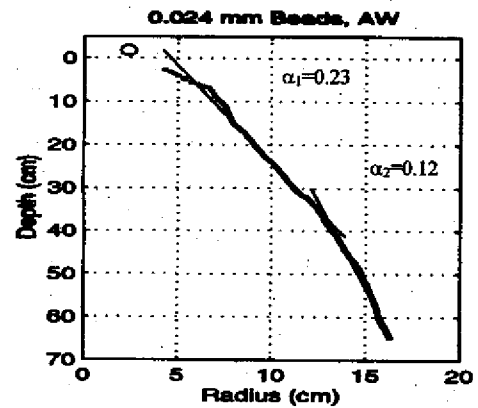


Figure 3. The entrainment coefficient (spreading rate) for two Group III Experiments.

Table 3. Cloud growth parameters for experiments shown in Table 1. Time t_t denotes the onset of turbulence (corresponding approximately to fully submerged conditions); t_c and z_c denote the time and depth associated with the transition to "circulating thermal"; α_1 and α_2 are spreading rates before and after this transition, and r_o , r_t and r_c are equivalent cloud radii before release, at the onset of turbulence and at the transition to circulation.

Experiment	α_1	α_2	$t_t(s)$	$t_c(s)$	$z_c(cm)$	r_o/r_t	r_o/r_c
Group I Experiments							
3.18 cm cyl., dry	0.18	0.14	0.5	1.7	39	2.0	4.5
3.18 cm cyl., wet	0.17	0.18	0.27	2.3	51	3.3	5.1
4.45 cm cyl., dry	0.20	0.16	0.47	1.3	31	1.9	4.1
4.45 cm cyl., wet	0.22	0.14	0.30	1.3	26	2.3	3.9
Group II Experiments							
40 cm ³ H ₂ O, Sus., AW	0.27	0.18	0.13	1.0	19	2.3	3.3
40 cm ³ H ₂ O, Sus., BW	0.29	0.18	0.40	1.4	23	2.0	3.8
40 cm ³ H ₂ O, Sus., AW	0.23	0.16	0.20	1.4	28	2.4	3.9
17 cm ³ H ₂ O, Sus., AW	0.31	0.19	0.17	1.1	22	2.7	4.0
Group III Experiments							
0.024 mm beads, AW	0.23	0.12	0.20	3.0	38	2.8	5.4
0.024 mm beads, BW	0.28	0.20	0.40	2.7	29	2.6	4.5
0.010 mm beads, AW	0.27	0.20	0.13	5.2	55	6.8	6.8
0.010 mm beads, BW	0.29	0.24	0.27	2.6	33	4.8	4.8



Figure 4. Sediment trap locations for determining "stem" mass distribution for 0.010 mm "BW" silt experiment.

LOSS OF FINES

Sediment trap experiments indicated that failure of particles and fluid to be initially incorporated into the cloud represents the main mechanism through which sediment is lost to the environment. Material not initially incorporated into the cloud formed a narrow "stem" behind the cloud, which contained as much as 30% of the original mass depending on the release conditions (see Figure 4). Sediment collected on traps placed at different depths relative to the passing cloud showed that much of the "stem" material was either re-entrained into the cloud later in descent or reached

the bottom shortly after it. Material not incorporated into the "stem", which may be advected by ambient currents, was found to be only a small fraction (< 1%) of the original mass.

CONCLUSIONS

Particle clouds transition from an initial "turbulent thermal" regime to a "circulating thermal" regime when their radius grows by about a factor of four relative to the prerelease radius. Fine particles ($N_c < 10^{-4}$) exhibit constant spreading throughout both regimes characterized by ($0.2 < \alpha < 0.3$), but significant sensitivity to initial water content and momentum. Larger particles exhibit a decrease in spreading from $0.2 < \alpha_1 < 0.3$ to $0.1 < \alpha_2 < 0.2$ following the transition. For water depths greater than about 100 m, this variation should be included in model simulation. Finally, the major cause for particle loss is failure of material to be incorporated into the plume, rather than any observed "stripping" mechanism.

ACKNOWLEDGMENTS

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Disposal of Boston Harbor Sediments into in-Harbor CADS: Minimal Water Quality Effects

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ABSTRACT: Maintenance and improvement dredging of portions of the federal channels servicing Boston Harbor (MA), as well as adjacent berth areas occurred from summer 1998 until spring 2000. Maintenance material (approximately 1,000,000 cy) was found to be unsuitable for unconfined open water disposal during the environmental impact assessment process. Assessment of disposal alternatives identified areas within the footprint of the federal navigation channel upstream of subsurface obstructions (vehicular tunnels) as the preferred option for constructing deep cells for containing the dredged silt material. Water quality modeling, using worst-case assumptions, during the environmental impact assessment process indicated that this type of disposal could be accomplished with minimal water quality impacts. Permit requirements were developed to include a water quality monitoring program that tested the various disposal scenarios that were anticipated to arise. This paper details the results of the monitoring program.

The monitoring program included tracking of the turbidity plume that was predicted to result from disposal from each scow. In addition, various sediment sources (specific channels and berths) and disposal locations were targeted for turbidity and water chemistry monitoring. These scenarios were selected to be representative of the typical project conditions as well as the worst-case conditions. In most cases, the disposal plume was so negligible that it was difficult to identify. No parameters tested were found to exceed applicable water quality criteria. It is concluded, therefore, that, as predicted, maintenance dredging of portions of Boston Harbor was accomplished with no substantial water quality effects.

Key words: CAD, water quality monitoring, turbidity plume, impact assessment, contaminated sediments

BACKGROUND

Surficial sediments from the channels and berths proposed for deepening were extensively tested for chemical and physical properties, biological effects and water column effects during the developing of the draft EIR/S for the Boston Harbor Navigation Improvement and Berth Dredging Project (BHNIP). Results are detailed in the DEIR/S (Massachusetts Port Authority and

U.S. Army Corps of Engineers 1994). Comparison of chemical and physical results to the Massachusetts Department of Environmental Protection (MDEP) standards for assessing dredging material disposal options showed that most surface sediments exceeded the allowable limits for unconfined open water disposal. Further bioassay testing indicated that the potential for sublethal effects existed. Thus, it was determined that none of the surface sediments could be disposed at the Massachusetts Bay Disposal Site.

Excavation of deep cells within the BHNIP footprint in the federal channels was identified as

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the most environmentally sound disposal option (Massport and USACE 1995). On the plus side, contaminated sediments would remain near the source; and, capping would sequester contaminants. Some concerns remained, however. Elutriate results had indicated that some parameters could be dissolved in the water column during disposal (Massport and USACE 1994). As Boston Harbor has been experiencing dramatic improvements in water quality as a result of Massachusetts Water Resources Authority's (MWRA) activities (reductions in CSOs, cessation of sewage sludge disposal), there was a concern that disposal in-harbor could impair these improvements, even temporarily.

Water quality effects of disposal in Boston Harbor were evaluated during the EIR/S process using a combination of the STFATE and WQMAP models (ASA 1995). Assuming that disposal of sediments containing the highest concentrations of contaminants observed took place in a single location in the harbor on a daily basis, the model predicted that a steady-state would develop in which an area of slightly increased suspended sediments and slightly elevated (but below water quality criteria) concentrations of parameters such as copper, mercury and PCBs would persist until disposal was completed. Plume dimensions would vary according to the tide, with gradual dispersion down the harbor.

To address the concern that flood tides would cause waterborne disposed sediments to build up in the upper inner harbor and to allow the largest volume of water for dilution, MDEP required that the dredger dispose only around high slack tide. In addition, they established a water quality monitoring plan to assess the areal extent of the influence of individual and cumulative disposal events. Various situations triggered monitoring, including: early disposal episodes in each tributary (Mystic and Chelsea Rivers), disposal of high volumes of sediments on a given tide, disposal of the more highly contaminated berth sediments, and limited remaining capacity of a cell.

MONITORING COMPONENTS

Four types of monitoring were conducted: areal extent of the turbidity plume, water quality at the edge of the mixing zone, dissolved oxygen in

bottom waters above uncapped cells, and bioaccumulation (Table 1). For the turbidity plume tracking and turbidity measurements during water quality monitoring, data were collected using a YSI 6920 turbidometer interfaced with differential GPS using HydroPro software that recorded turbidity and position at one-second intervals (approximately every 2-5 feet traveled).

Table 1. Monitoring components, as required by the Massachusetts Department of Environmental Protection Water Quality Certificate.

Type	Description
Turbidity Plume	One-two hours post-disposal; surface, mid (~20-25 ft) - and bottom (~40-50 ft) depths; 300 ft upcurrent to 1000 ft downcurrent
Water Quality	See Table 2; all samples composite of mid- and bottom water
Dissolved Oxygen	Near bottom (within 1-2 ft of substrate) conditions in late summer-early fall over uncapped cells
Bioaccumulation	Long-term exposure to mussels from dredging and disposal

Water quality monitoring was initiated by determining the location of the densest portion of the plume both laterally and vertically along a transect 300 ft downcurrent of the disposal cell. This was accomplished by towing a turbidometer along the transect extending 200 ft beyond the sides of the cell within three feet of the bottom and in the middle of the water column. Turbidity, depth, and DGPS coordinates were displayed and recorded continuously during these tows. The location of the highest turbidity readings was reoccupied and confirmed by collecting a vertical turbidity profile. Water samples were collected at this site. During each water quality monitoring event, a series of five samples was collected (Table 2). Figure 1 shows the layout of the sampling stations for a typical water quality monitoring event. Water chemistry results were compared to the water quality criteria developed by MDEP. Samples collected 0.5 and 1.0 hour after disposal were compared to the acute criteria. Samples from 4-6 hours after disposal

were compared to the chronic criteria. Dissolved oxygen immediately above the bottom was collected in order to ascertain whether the presence of exposed silts at depths greater than the surrounding bottom exacerbated hypoxic conditions commonly observed in the late summer-early fall in Boston Harbor.

The potential exposure to resident organisms in the upper harbor to contaminants released into the water column by BHNIP activities, including both dredging and disposal, was evaluated by placing mussels in various locations surrounding the work area and at a reference site in the lower inner harbor. Mussels were tested for bioaccumulation of selected metals (As, Cd, Pb, Hg) and organics (PCBs, PAHs) after exposure for a period of two months.

Table 2. Water quality monitoring program involving dissolved As, Cd, Cr, Cu, Ni, Pb, Zn; total Hg, PCBs.

Location	Time	Comments
Reference	Prior to disposal	Away from influence of dredging or previous disposal
Mixing zone boundary (300 ft down-current of cell boundary)	0.5 hr after disposal	In area of highest turbidity
	1 hr after disposal	
	4-6 hrs after disposal	Composite over two samples at least an hour apart
Reference	4-6 hrs after disposal	Upcurrent of disposal; composite over two samples at least an hour apart

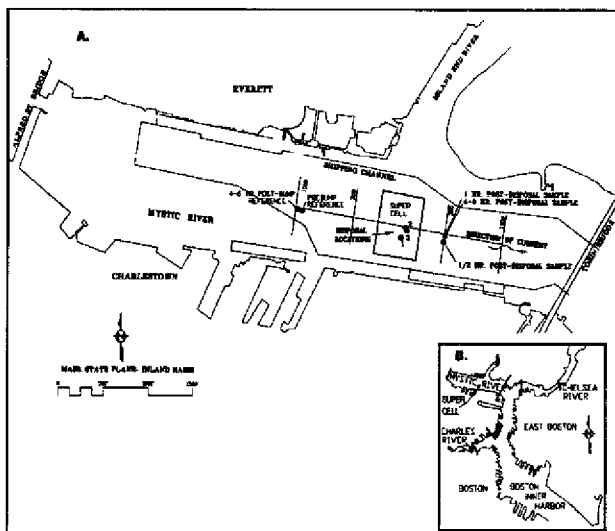


Figure 1. Layout of water quality monitoring stations in the Mystic River (A) and relation to Boston Inner Harbor (B).

RESULTS

TURBIDITY PLUME

Turbidity rarely exceeded background levels in near surface waters. This was an expected result because disposal was from a bottom-opening scow whose loaded draft was well below the water surface. At mid-depth, turbidity was occasionally elevated, but no clearly defined plume was detectable.

A restricted turbidity plume was typically evident near the bottom of the water column. Generally, however, turbidity levels during the period from one to two hours after disposal (up to about 30 NTUs) were only slightly higher than ambient levels (<10 NTUs) in bottom waters.

WATER QUALITY

Water quality sampling was the most extensive component of the monitoring program. Of the variables monitored, several (arsenic, cadmium, and nickel) were never detected, despite laboratory detection limits well below (0.5 to 3 orders of magnitude) the chronic water quality criteria levels. Total PCBs were only detected in 3% of the samples tested. Most metals were observed frequently at the reference station and the edge of the mixing zone (Table 3). Dissolved lead and total mercury were detected more frequently in the samples at the edge of the mixing zone than in the reference samples, suggesting that disposal activities could have resulted in some release of these chemicals. No metal was found in concentrations that exceeded acceptable water quality conditions (Table 4).

Because disposal at high tide was found to have limited effects on water quality, MDEP allowed the dredger to dispose of sediments at low tide, provided water quality effects were documented. Results were similar to high tide disposal – no parameter tested was found to exceed appropriate water quality criteria.

DISSOLVED OXYGEN

The original Water Quality Certificate required that disposal cells be capped with sand in two weeks to two months following final disposal. Initial capping efforts indicated, however, that

Table 3. Frequency of detection for variables tested during BHNIP monitoring.

Variable	Pre-dump Reference	+ 0.5 hr	+1.0 hr	+4-6 hr	+4-6 hr Reference
Cr	60%	40%	40%	60%	40%
Cu	46%	15%	0%	8%	0%
Pb	69%	92%	92%	85%	77%
Hg	77%	85%	92%	77%	77%
Zn	80%	80%	100%	80%	100%

(percentage of times detected out of a possible 13 monitoring events except Cr and Zn which were monitored only during five berth sediment disposal events)

Table 4. Range of concentrations (ug/l) of frequently observed variables compared to MDEP water quality criteria.

Variable	Pre-dump Reference	+0.5 hr	+1.0 hr	+4-6 hr	+4-6 hr Reference
Pb	0.06 – 0.13	0.07 – 0.28	0.07 – 0.29	<0.05 – 0.15	0.05 – 0.26
Pb criterion	n/a	210 (acute)		8.1 (chronic)	n/a
Hg	<0.005-0.015	<0.005-0.036	<0.005-0.032	<0.005-0.016	<0.005-0.017
Hg criterion	n/a	1.8 (acute)		0.025 (chronic)	n/a
Zn	2.2 – 3.2	<2.0 – 5.9	2.3 – 3.2	<2.0 – 4.1	2.2 – 3.1
Zn criterion	n/a	90 (acute)		81 (chronic)	n/a

capping could be accomplished more effectively if the disposed sediments were allowed a longer period for consolidation prior to sand placement. Several cells remained uncapped during the late summer-early fall in 1999, a period when Boston Harbor has often experienced hypoxic conditions. Because the uncapped cells were several feet deeper than the adjacent harbor bottom, there was concern that they could create pockets of exceptionally low dissolved oxygen. From August through October, however, dissolved oxygen in bottom waters over the cells followed a similar pattern to that at several reference locations. Bottom dissolved oxygen was lowest in late September at all stations, between 4 and 5 mg/L. Vertical profiles collected during late September indicated that the greatest decrease occurred within the top 20 to 30 feet of the water column. From about 30 feet to the bottom,

dissolved oxygen was stable ranging from about 4.5 to 5 mg/L.

BIOACCUMULATION

Mussels were deployed in the Mystic River for a period of two months about 1000 ft west of the end of the federal channel (stations M1 and M2) and about 1000 (station M3) to 2000 ft (station M4) east of easternmost disposal cell, as well as at a reference station about 1 mile down harbor from the Mystic River. During this period, dredging and disposal were actively occurring within the Mystic River channel.

Analysis of variance was used to compare tissue concentrations of arsenic, cadmium, lead, mercury, total PCB, and total PAH across stations. Cadmium was not detected in any sample. There were no significant differences in mercury concentrations among stations. Results for the other variables are shown in Table 5.

DISCUSSION

In general, the results of the water quality monitoring program support the conclusion of the predictive modeling that water quality of Boston Inner Harbor would not be substantially impaired by disposal activities, although the observed plume was much smaller than predicted and it did not persist. Part of this result can be attributed to the fact that disposal activities did not unfold exactly as assumed for the model. In particular, in-harbor disposal did not occur on a daily basis for the duration of the project because that was not the most efficient operating mode for the dredger. In addition, many barges contained a lower volume of sediments than assumed. The sediment quality assumed for

Table 5. Results of ANOVA comparing mussel tissue concentrations of selected variables. The sampling stations are listed in order of decreasing concentration; underlined stations are statistically similar.

Variable	Significant Differences
Arsenic	<u>Ref</u> M4>M1>M2>M3
Lead	M3>M4 M2 <u>Ref</u> M1
Total PCBs	<u>M1</u> M2 M4 M3 <u>Ref</u>
Total PAHs	<u>M1</u> M2>M4 M3>Ref

the model was worse than typical conditions.

The mussel study did show some bioaccumulation of arsenic, lead, PCBs and PAHs. Within the harbor there are other potential sources of chemicals that may influence mussel tissue concentrations. Tissue concentrations of arsenic were highest at the reference site, suggesting an in-harbor source. The highest lead levels were at station M3 and M4, located near the Tobin Bridge, which is painted with lead paint. The highest lead level observed in this study was nearly an order of magnitude lower than levels observed at the MWRA reference station (in the lower inner harbor) in 1996 (Mitchell *et al.* 1997). Both PCBs and PAHs exhibit a down-river pattern, suggesting that the ultimate source was farther up the Mystic River. Levels of total PCBs in mussels at this study's reference stations were similar to those observed at the MWRA reference station in 1996. Total PAH levels at the BHNIP reference station were lower than at the MWRA reference station in 1996.

In conclusion, the use of in-harbor CADs was an effective method for disposal of contaminated sediments in Boston Harbor. Water quality impacts were minimal and did not persist substantially beyond the immediate disposal event, as evidenced both by the water quality monitoring and the bioaccumulation study. Uncapped cells appeared not to compromise near-bottom water quality.

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Experimental Investigation of Strength Development in Dredged Marine Sediments

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ABSTRACT: Placement of a sand cap imposes impact and static loads on the underlying dredged material. Successful capping requires that the dredged materials consolidate for a time sufficient to develop the necessary strength to support the cap. Hence it is of critical importance to understand the process of shear strength development in weak sediments.

The research effort presented here is designed to investigate the consolidation and strength development behavior of Boston Harbor sediment in different effective stress regimes. The tests are performed on the sediment extracted from Reserved Channel, with natural water content of about 160%. The range of effective stress spans from 0.1 g/cm² to 3000 g/cm², which corresponds to the depth range from zero to 300 feet in a sub-aqueous deposit of the dredged material. Consolidation is progressively carried out under self-weight conditions, surcharge conditions, and finally in a Constant Rate of Strain (CRS) Test. The Automated Fall Cone Device is used to measure the shear strength of the sediment.

The results show that above a certain value of effective stress, the shear strength at a given effective stress is independent of the thixotropic effect and the initial water content. Below this value of effective stress, a consolidation model may be used in conjunction with our data to estimate the shear strength for a dredged material as a function of consolidation time and initial water content. This method for the estimation of shear strength provides a basis for developing the guidelines for the optimal timing of cap placement.

Key words: capping, shear strength of weak sediments, consolidation, CAD

INTRODUCTION

The technique of Confined Aquatic Disposal (CAD) capping is often utilized for sequestering contaminated marine sediments. It involves excavation of subaqueous borrow pits which are subsequently filled with contaminated material and then capped with clean sediment. A CAD cell 500 ft long, 200 ft wide, and 40 ft deep was excavated, filled, and capped in a water depth of approximately

40 ft, as a trial project in Phase I of the Boston Harbor Navigation Improvement Project (ENSR, 1997). Extensive monitoring of the sand cap and an investigation of its performance in this project served to emphasize the need for better understanding of some critical aspects of capping process. The lack of adequate knowledge of the geotechnical properties of the dredged material was identified as a major issue of concern (SAIC, 1997).

Figure 1 shows a schematic diagram of a capped CAD cell. A successful capping operation requires that the underlying material has enough

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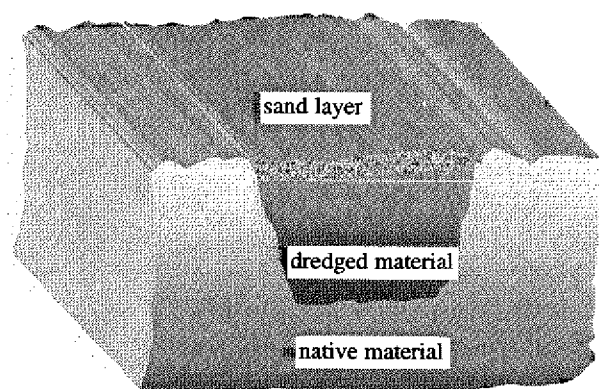


Figure 1. Schematic of a capped Confined Aquatic Disposal (CAD) cell.

shear strength to support the load of the overlying cap. Since the processes of dredging, transport, and deposition effectively remold the dredged material, its strength in the freshly-deposited state in a CAD cell is lower than its in-situ strength prior to dredging. With the passage of time, the shear strength of this material increases. If a cap is placed before it has developed the strength required to support the load, the cap will sink through the weak material and fail. On the other hand, the polluted dredged material continues to release contaminants into the water column during the time it stays uncapped. The cap, therefore, should be placed as soon as the dredged material is strong enough to support it, but no sooner. A related issue is the mode of cap placement, *i.e.*, whether the cap is placed in one operation or in incremental layers. To ascertain the proper cap-placement mode and timing from the properties of a given dredged material, a methodology is required that is based on the knowledge of shear strength development in dredged sediments.

Freshly-deposited dredgings are a fluid-mud mixture at high water content, with strength characteristics that are known to be markedly different from those of the compact soils. The undrained shear strength of these materials can be lower than 1 g/cm^2 ($1 \text{ g/cm}^2 = 98 \text{ N/m}^2$), and hence their classification as soft sediments.

This paper describes the difficulties in measurement of very low values of shear strength, and presents sample results obtained with the Massachusetts Institute of Technology Automated Fall Cone Device, a technique that enables measurement of shear strength as low as 0.03 g/cm^2 .

UNDRAINED SHEAR STRENGTH

The bearing capacity for a sediment foundation is defined as the mean total stress on its load-bearing surface when this surface is at the point of collapse. A cap is expected to be stable when the loads imposed by it on the underlying material are smaller than the bearing capacity of this material. In subaqueous capping projects where the underlying dredged material consists mainly of clay fractions, the consolidation time for the underlying deposit is much greater than the cap loading time. The situation, therefore, corresponds to undrained loading and the sediment strength in this case depends mainly on pre-load conditions.

Furthermore, the cap material is often dispersed on the dredged sediment (with the use of a split-bottom barge, for example) and does not penetrate the underlying material. The bearing capacity, q_u , in this case is given as a direct function of the undrained shear strength of the underlying material:

$$q_u = c_u N_c$$

if the undrained shear strength, c_u , is assumed to be constant in the underlying deposit. N_c is a dimensionless bearing capacity factor (Lambe and Whitman, 1969).

The actual value of undrained shear strength in a sediment deposit is a function of both depth and time. Strength increases with depth, due to increase in vertical effective stress. The depth profile of strength changes with time, and this time-related increase in strength is known to be a complicated process that depends upon, among other things, water content as well as the magnitude of effective stress (Zreik, 1994). It is acknowledged that two different mechanisms contribute to the gain in shear strength of sediments. The first is the consolidation-related strength gain, which is the result of solid particles coming closer as the pore water is squeezed out of the deposit. The second contribution comes from thixotropy, which is defined as the reversible time-dependent increase in strength of the material occurring under conditions of constant composition and volume (Mitchell, 1960).

Notwithstanding a wide range of situations where the shear strength of soft sediments is an important parameter, literature concerning this subject is scant. In comparison, the state-of-art in

understanding and predicting the strength behavior in classical soils is quite well developed (Ladd and Foott, 1974; Sheahan *et al.*, 1996). The discrepancy is explained by the difficulties encountered in measurement of very low values of strength.

MEASUREMENT OF STRENGTH IN SOFT SEDIMENTS

The devices most commonly used for strength measurements in soils are the shear vane and the fall cone penetrometer. Both are index tests and are able to measure shear strength of either undisturbed or remolded sediments. These tests are simple and quick, and can be performed on samples that are still in the coring tubes or barrels, thus preserving to a large extent the *in situ* water content. The lowest measurable strength for both these devices is in the range of 1–5 g/cm² (100–500 N/m²). A fall cone-type device is preferred for measurement of shear strength in soft sediments because a lab vane cannot measure very low values of strength (<1 g/cm²), due to the inability to measure very small torques (Zreik *et al.*, 2000). Furthermore, a fall cone device can provide a depth resolution of less than 1 cm, compared to 1.3 to 3.3 cm for the lab shear vane.

A modification of the traditional fall cone device was developed by Zreik (1991) for measurement of soil strength values as low as 0.03 g/cm² (3 N/m²). Figure 2 shows a schematic representation of the Automated Fall Cone Device (AFCD). It essentially consists of a precisely machined and weighted cone that is initially positioned such that its tip just touches the sediment surface. The cone is allowed to fall and penetrate the sediment sample under its own weight for a specified amount of time. The soil shear strength is inversely proportional to the square of the penetration depth. According to Hansbo (1957), the undrained shear strength, c_u , is given by:

$$c_u = k(W/d^2)$$

where W is cone weight, d is cone penetration, and k is a constant depending on the cone shape. Values of k for different cone angles are suggested by Houlsby (1982), based on a detailed theoretical analysis of the motion of a cone penetrating the horizontal surface of a soil.

The measurement system of AFCD is based on an AC-DC transducer. The cone is threaded to the

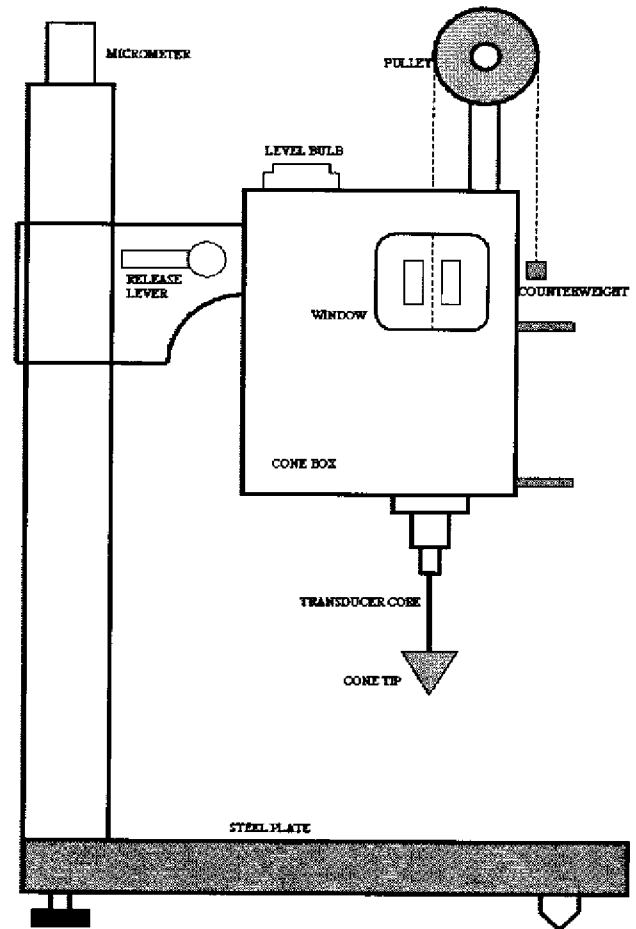


Figure 2. Schematic of the Automated Fall Cone Device (AFCD).

transducer core and this arrangement allows the measurement of cone displacement as a voltage output readable on a voltmeter. The release and clamping of the cone are controlled with an electronic timer. A pulley with a counterweight system allows the use of cones with a very small effective weight, thus enabling measurement of low values of undrained shear strength.

SAMPLE RESULTS

Remolded shear strength of kaolinite was measured at different water contents. For purpose of these tests, dry kaolinite powder was mixed with distilled water and the resulting paste was left to hydrate for one day. Distilled water was uniformly mixed into this paste to achieve the desired value of water content. Care was taken to minimize air

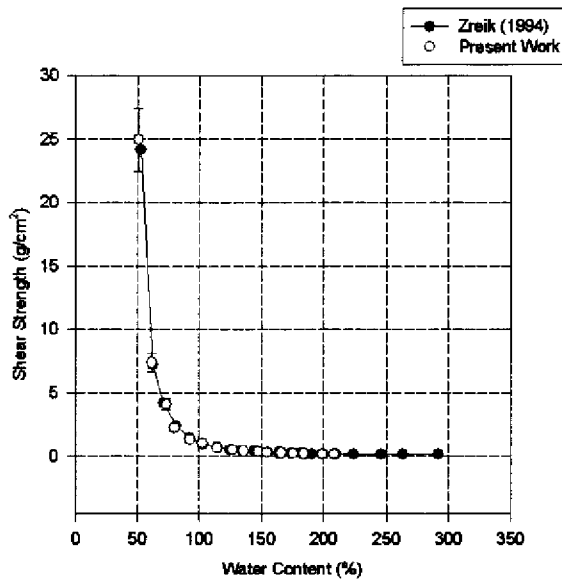


Figure 3. Variation in undrained shear strength of remolded kaolinite with water content.

entrapment during mixing.

Six to eight strength measurements were taken with the AFCD for each value of kaolinite water content. The average values of undrained shear strength are presented in Figure 3. The error bars enclose the interval of one standard deviation on each side of the mean value of the measurements. The figure also shows the results obtained by Zreik (1994) on the same material. The resulting comparison indicates excellent repeatability of AFCD measurements.

Strength measurements were also performed on the sediment retrieved from Reserved Channel in Boston Harbor, a site that was dredged under the Boston Harbor Navigation Improvement Program (BHNIP). This sediment was homogenized and characterized prior to testing. Table 1 shows the remolded shear strength of Reserved Channel sediment at three different water contents.

These measurements adequately demonstrate the reliability of the Automated Fall Cone Device in measuring very low values of undrained shear strength of sediments. This capability is the basis of an experimental research program currently underway at the MIT Geotechnical Laboratory, with the objective of understanding the process of strength development in consolidating dredged materials. Specifically, it aims to ascertain the relative contributions of effective stress and thixotropic strength gain to the total undrained

Table 1. Variation of undrained shear strength of remolded kaolinite with water content.

Water Content	Av. Shear strength (g/cm ²)	Standard Deviation
150%	0.45	0.037
200%	0.23	0.021
250%	0.17	0.019

shear strength. This understanding will provide the crucial input for modeling of strength development in consolidating dredged sediments.

ACKNOWLEDGEMENTS

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Propwash Modeling for CAD Design

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ABSTRACT: A numerical model has been developed to simulate near-bed velocities generated by ships' propulsion. The model incorporates theoretical descriptions of the geometry and velocity structure in a momentum jet. Field measurement programs have recently afforded the opportunity to validate the model. The model is a reliable tool for estimating the velocity at specified distances from the bottom. Its application is suited for determining potential for sediment suspension, and for design of a stable cap overlying erodible sediments.

Key words: propwash, CAD, bottom velocity, bottom scour, sediment suspension

INTRODUCTION

Confined Aquatic Disposal (CAD) sites are often located in open water and are usually subjected to effects of passing deep draft vessels, tugs, and small craft. Evaluating the hydrodynamic forces on surface sediment and the sediment cap is critical to CAD design. Integrity of the sediment cap is essential to the success of a Confined Aquatic Disposal site in preventing dispersal of sediments contained within the CAD. The following describes the development and application of a numerical tool for calculating near-bed velocities generated by a ship's propulsion and the resulting potential for scour of bottom sediments.

A numerical model is required to investigate vessel effects for many applications. The JET-WASH model was developed to operate with input of sediment and propulsion characteristics and water depth, and to output velocity at a given distance aft of the vessel and radially from the velocity jet centerline, or at a known distance above the bottom. Example applications of the model are to evaluate:

- Potential for vessel operation to harm marine plants, such as eelgrass;
- Suspension and transport of fine sediments that would degrade nearshore habitat; and

- Penetration of a sediment cap that is intended to isolate the underlying material.

Increasing concerns about sediment quality in marine industrial areas and habitat preservation for endangered fish species in Puget Sound (Washington State) was the impetus for development and testing of a model that could quantify hydrodynamics and sediment transport in the above listed applications. The writers coded formulas published in the engineering literature into a calculation model named JETWASH. Planning and environmental studies for maintenance activities by marine carriers provided opportunities to make field measurements that served to validate the JET-WASH model.

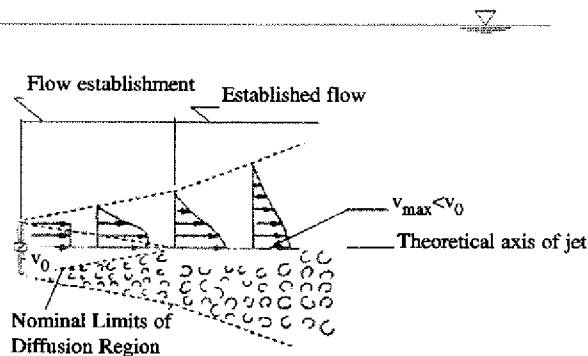
THEORETICAL BASIS OF MODEL

Researchers have advanced mathematical descriptions of the velocity field generated by jets discharging into a fluid body and by propellers rotating in a fluid. Formulas developed by Albertson *et al.* (1948), Liou and Herbich (1976), Blaauw (1978), Verhey (1983), Fuerher *et al.* (1987) describe the velocities and geometry of the turbulent jet as it expands into a volume of water. The structure of the water velocity is described mathematically in two zones (Figure 1). The initial velocity is calculated from details of the propeller and persists in the zone directly behind the pro-

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propeller. The core of initial velocity in this first zone is unaffected by transfer of fluid momentum to the surrounding water. Downstream from the first zone, water velocity is developed through transfer of momentum from the core of initial velocity to the surrounding water. The edge of the cone of expanding turbulence in this second zone experiences lower velocity than the centerline, and the centerline velocity diminishes with increasing distance from the source.

Figure 1. Geometry of initial velocity zone and momentum jet formed by the propulsion system.



Hydrodynamic research shows that the velocity required to move sediment particles in water depends on several parameters. Succinct combinations of the pertinent parameters are the Shield's parameter (a ratio of the threshold boundary shear stress to the immersed weight of a sediment particle) and the boundary Reynolds number (a ratio of inertial forces to viscous forces acting on the particle comprising the bottom). Cheng and Chiew (1999) developed relationships between these two parameters for the case of suspended load. Their results yield the shear velocity corresponding to the initiation of suspension of sediment particles having a given diameter. Flow causing suspension of sediment particles initially at rest is termed the scouring velocity. The flow velocity at a selected distance above the sediment bed necessary to suspend a given size sediment in the flow is determined from the critical shear velocity and the equation for the logarithmic velocity distribution in a fully turbulent, hydraulically rough boundary layer (Middleton and Southard 1984, p. 152). Modeled or measured velocity can then be compared with the theoretical suspension velocity (in the

absence of sediment concentration measurements) to determine if the threshold for suspension is exceeded in the particular conditions.

Research reported by Hamill (1988) provides a means of calculating scour depth in bottom sediment by a propeller. Empirical relationships developed by Hamill among initial velocity, propeller tip clearance above the bottom, duration of exposure to the propwash, propeller diameter, and sediment size were formulated to calculate the maximum scour depth.

FIELD MEASUREMENTS

A coefficient describes the spread of the momentum jet in the fluid, or the angle of the edge of the jet with respect to the centerline. The coefficient has been evaluated by several researchers with laboratory and limited field studies. Pacific International Engineering conducted field data collection to validate the model with measured velocities and known propulsion characteristics.

DATA COLLECTION

Velocities were measured at the bottom with an Acoustic Doppler Velocimeter (ADV), which relayed data through a cable to a computer aboard a small survey boat anchored nearby. Figure 2 shows the weighted instrument frame on which is mounted an ADV, a video camera, and compass. Figure 3 shows one measurement site marked with buoys. A Global Position System (GPS) unit was mounted on board the test boat above the propeller or jet pump nozzle for recording position. The test boat position data were time stamped as they were

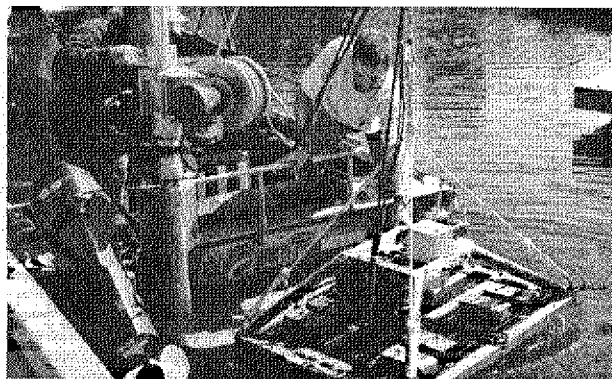


Figure 2. Velocity meter mounted on frame and suspended from boat davit (before deployment on the bottom).

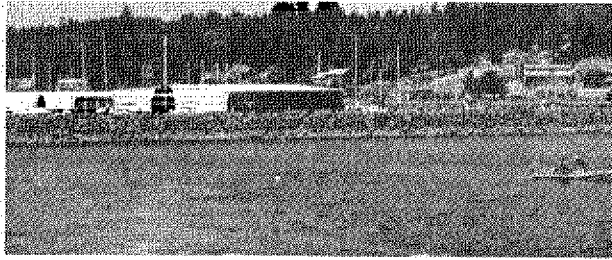


Figure 3. Test area marked with buoys and survey boat at anchor.

recorded on a computer aboard the test boat. The captain was directed to move the boat directly over the velocity meter during the tests. The goal was to capture the direct flow of the velocity jet as fully as possible. As a test run began, the start time and maneuver to be simulated were communicated between the survey boat and the test boat by radio. Engine rpm was monitored in the wheelhouse of the test boat and manually entered on the computer that recorded the GPS signal. The velocity was measured 25 cm above the bottom. The horizontal and vertical components of velocity were sampled at 0.04-second intervals. Velocity data were recorded through a cable on the survey boat computer, which was also synchronized with the GPS signal.

DATA PROCESSING

The horizontal and vertical components of measured speed were combined, resulting in a time series of speed for each test. The peak bottom velocity is of interest because that is the quantity that is most critical to determine the potential for scouring of bottom sediments. The velocities determined at 0.04-second intervals were converted to a 1-second-average velocity time series. The duration of the period of high velocity indicates the length of time during a particular maneuver that potential bottom-scouring conditions could persist if a threshold velocity was exceeded. Synchronous boat position, engine speed, and bottom velocity data reveal conditions under which a particular velocity pattern is generated. One example of a velocity time series is shown in Figure 4.

MODEL VERIFICATION

Boat and propulsion characteristics and site conditions were input to the JETWASH model. Model output is summarized as a graph of velocity

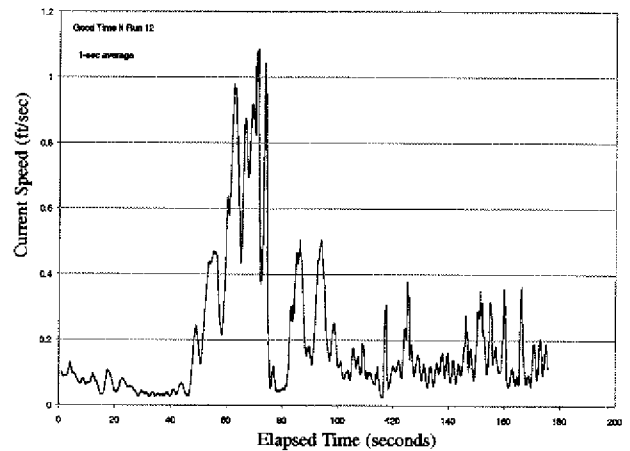


Figure 4. Measured velocity time series for test vessel.

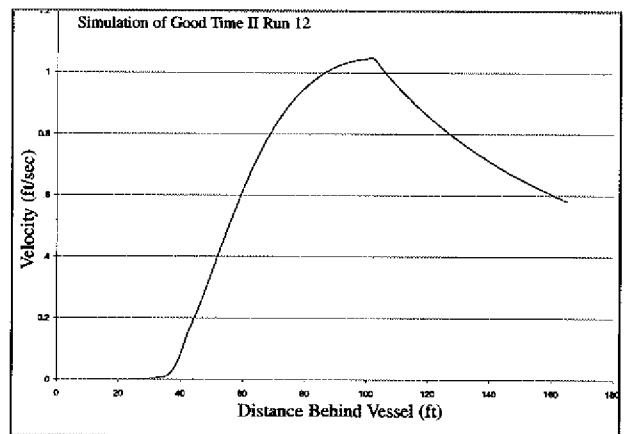


Figure 5. Predicted bottom velocity for test vessel.

at a distance of 0.83 ft (25 cm) above the bottom that would be experienced at given distances behind the boat. The coefficient that describes the expansion rate of the momentum jet was determined to be 0.3 using velocity measurements of a pair of ADVs separated by 12.5 ft (3.8 m) mounted on a vertical. Separate velocity measurements, made 0.83 ft (25 cm) above the bottom, were used for model verification. Figure 5 is a graph of simulated velocities for the conditions represented in Figure 4. The measured peak near-bottom velocity indicated in Figure 4 is 1.1 feet per second (33.5 cm per sec). The simulated peak near-bottom velocity indicated in Figure 5 is 1.05 feet per second (32 cm per sec). Other runs involving both propeller- and jet pump-powered vessels were simulated. The average velocity agreement, expressed by measured minus modeled as a fraction of measured velocity, is -0.1 , which is judged to be

good agreement.

The underwater video did not indicate significant sediment disturbance, although that provides only a qualitative evaluation at best of the sediment suspension calculations. The velocity necessary to suspend sediment of a given size was calculated as described above for the test conditions. Results are listed in the table below. The measured and modeled velocities do not exceed the velocity for suspension of bottom sediments of the sizes down to very fine sand. The comparison confirms at least qualitatively that the simulated velocity magnitude and the procedure for estimating suspension of bottom sediments by near-bottom velocities generated by vessel propulsion are correct for this type of application.

Table 1. Velocity to suspend sediment of given size.

Mean Sediment Diam. (mm)	Velocity at Reference Height Above Bed*	
	mm/sec	ft/sec
4	2176	7.14
2	1590	5.22
1	1007	3.31
0.5	675	2.22
0.25	569	1.87
0.125	496	1.63

*Reference height is 0.83 ft above bottom
Simulated conditions are Puget Sound water

APPLICATION

The JETWASH model has been applied at several locations for purposes of design and environmental effects investigations. Example applications in Puget Sound are:

- Colman Dock Resuspension Study—Investigated potential for resuspension of contaminated bottom sediments near a ferry dock.
- Vashon Island Eelgrass Disturbance Study—Investigated the conditions under which ferry operations would dislodge eelgrass from the bottom.
- Southworth and Kingston Ferry Terminals—Investigated bottom scour and transport of fine sediments onto eelgrass beds in the vicinity of proposed ferry docks.
- Foss and Hylebos Waterways—Aided in design

of sediment caps to confine contaminated sediments in a deep-draft waterway.

- Mukilteo Passenger-Only Ferry – Aided in selection of vessel for temporary use as ferry that would not cause disturbance of bottom sediments.

SUMMARY

A numerical model was developed and verified for simulating the velocity pattern in a jet created by a ship's propulsion system. A calculation procedure was developed for determining the threshold size of sediment suspended in a specified flow field. Observation of the bottom showed the sediment suspension calculation procedure is accurate in predicting sub-threshold conditions. Further research can confirm the accuracy in scouring conditions.

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Evaluating Dredged Material in a Sub-Channel Confined Aquatic Disposal Environment: Experience from the Boston Harbor Navigation Improvement Project

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ABSTRACT: Sediment samples were collected from one of the Boston Harbor in-channel confined aquatic disposal (CAD) cells prior to and after cap placement in order to evaluate the geotechnical behavior of the dredged material. Core and grab samples were intensively sampled to assess a suite of physical properties that would allow assessment of the change in strength of material resulting from both self-weight consolidation and the overlying load of the sand cap. The data indicated that the *in situ* cohesion and strength of the sediment were altered by the dredging process, resulting in sediment with high water content and low shear strength. There were no significant differences in sediment properties following five months of self-weight consolidation, whereas the most significant change was an increase in shear strength of the dredged material after capping. In the short-term, results can be used to develop field protocols to assess sediment strength in future CAD projects; in the long-term the data will be useful in developing quantitative guidelines for assessing geotechnical "cap-readiness" of disposed dredged material in a confined environment.

Key words: consolidation, shear strength, CAD, bulk density, core logger, multibeam, Boston Harbor, MA

INTRODUCTION

The Boston Harbor Navigation and Improvement Project (BHNIP) has provided an opportunity to evaluate the efficacy of capping dredged material considered unsuitable for offshore disposal in a confined sub-channel environment. In order to evaluate the critical geotechnical properties that determine the "cap-readiness" of dredged material in a confined setting, a series of surveys were conducted on confined aquatic disposal (CAD) cell M2 in the Mystic River. Geotechnical cores, grab samples and multibeam

bathymetry were collected during multiple phases of the project. First, samples were collected from the Mystic River to represent *in situ* sediment prior to dredging. Sediment samples were also collected during disposal from the transport barge. Finally, samples were collected from cell M2 a) after deposition of the dredged material; b) prior to the placement of cap material; and c) after placement of the cap material.

Capping has been used to confine contaminated sediments in offshore environments, showing that lower density fine-grained sediments can successfully be covered with higher density sand (e.g., SAIC, 1995; Poindexter Rollings, 1990; Silva *et al.*, 1994). Empirical geotechnical data

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collected from these capping projects have indicated that the disposed dredged material had consolidated sufficiently to a bearing strength capable of maintaining a capped stratigraphy. However, no quantitative data existed, to provide guidance on how to determine when sediments have sufficient strength to be capped, and what geotechnical measurements were necessary to determine cap-readiness.

Due to the differences in the geotechnical framework of the in-channel CAD cell and that of the open-water capped sites, a lack of predictive data hindered the ability to design the operational parameters that would optimize capping success. Hence, early results from the BHNIP showed that due to the geotechnical nature of the dredged sediments increased consolidation time and modified operations would be required for successful capping of a CAD cell. However, the amount time required to allow the sediments to consolidate to a state of cap-readiness was essentially unknown. Through integration of multiple survey techniques (*i.e.* multibeam bathymetry; subbottom profiling; geotechnical analysis of sediments; and detailed knowledge of material placement) and the use of geographic information system (GIS) tools, a better perspective of CAD cell dynamics was gained.

THE BOSTON HARBOR NAVIGATION IMPROVEMENT PROJECT

A more detailed overview of Boston Harbor Navigation Improvement Project (BHNIP) and the geotechnical investigation are included in a summary report submitted to the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station (WES) (SAIC, 2000). The main ship channel, three tributary channels (Mystic River, Chelsea River, and Reserved Channel), and several terminals and berths in Boston Harbor were deepened as part of the BHNIP through the spring of 2000 (USACE and Massachusetts Port Authority, 1995). The BHNIP was a joint project between the USACE, New England District (NAE) and the local sponsor, the Massachusetts Port Authority (Massport). The first phase of the project was conducted in the summer of 1997 when Conley Terminal was dredged (ENSR, 1997). In the summer of 1998, the second phase of BHNIP was contracted to Great Lakes Dredge and Dock (GLDD, Oak Brook, IL), for the 1998 filling of CAD cells

M4, M5, and M12; the 1999 filling of cells M2 and Super Cell; and the completion of cells M8-11 and M19 in Spring 2000. Funding for the Geotechnical Investigation of CAD cell M2 was provided by the USACE Monitoring Completed Navigation Projects (MCNP) program, which supplemented monitoring efforts sponsored by NAE and Massport.

GEOTECHNICAL INVESTIGATIONS OF CAD CELL M2

Following the experience from the first three CAD cells constructed during Phase 2, several operational changes were made to the capping process, including increasing the time allowed for consolidation. In addition, a plan was devised for additional studies to be conducted on a typical in-channel CAD cell. To this end, the sediments being placed in CAD Cell M2 were sampled and evaluated for engineering properties during several phases. Samples were collected prior to dredging (In Situ Survey), during transport (Barge Sampling), immediately after placement in the CAD cell (T0 Survey), immediately prior to capping (T1 Precap Survey), and after capping (Postcap Survey). This paper will primarily address CAD Cell M2 and the behavior of the material at the various stages of the geotechnical investigation.

Several factors challenged the conventional wisdom related to capping dredged sediments. First, the material disposed in the CAD cells contained high volumes of pore water. Second, the BHNIP CAD cells were dredged in a lithology called Boston Blue Clay (BBC) which is highly cohesive and impermeable. Geotechnical studies conducted at open water disposal sites have shown that dredged material deposited on the seafloor goes through a stage of self-weight consolidation, and then is further compressed by successive layers of cap material placed on top of it (*e.g.*, Poindexter Rollings, 1990; Silva *et al.*, 1994). In the case of the BHNIP CAD cells, sequential bathymetric surveys showed an initial phase of rapid consolidation. But after the initial height change, further consolidation was restricted by a lack of ability for side and bottom advective flow (escape) of pore water due to the nature of the BBC in which the CAD cell existed. Thus, timing of consolidation was an issue, as well as providing quantitative data that could be used in other projects to

indicate when the sediments would be ready to accept cap material.

CHRONOLOGY OF THE GEOTECHNICAL INVESTIGATIONS

In June 1999, samples were collected from the Mystic River to represent *in situ* sediment prior to dredging. Sediment samples were also collected during disposal from the transport barge. Finally, samples were collected from cell M2 a) after deposition of the dredged material, June 1999; b) prior to the placement of cap material, October 1999; and c) after placement of the cap material December 1999.

METHODS

SAMPLE COLLECTION AND PROCESSING

The *in situ* (Mystic River, MR), T_0 and T_1 surveys included gravity cores and sediment grab samples, collected by SAIC (Newport, RI). Twenty-foot vibracores were collected by GLDD and Ocean Surveys, Inc. (OSI) in support of the Postcap survey and delivered to SAIC for postprocessing. Laboratory processing included the use of a Multi-Sensor Track (MST) core logger at the University of Rhode Island's Graduate School of Oceanography (GSO). The core laboratory was used to log the whole cores collected as part of the MR, T_0 , T_1 and Postcap surveys. The same core logging procedure was used for all core surveys. Measured parameters included density, magnetic susceptibility, and P-wave velocity. Additional information on the individual MST measurements can be found on the Internet at the following address:

<http://www.odp.tamu.edu/publications/tnotes/tn26> (Blum, 1997; Physical Properties Handbook, Ocean Drilling Program Technical Note 26, Texas A&M University). After logging, all cores were split, visually described, and digitally photographed. Sediment sub-samples were collected by SAIC technicians and sent to Applied Marine Science, Inc. (AMS) in League City, Texas. Samples were collected from both the cores and grabs and analyzed for physical property measurements, including wet bulk density (EM 1110-2-1906), water content

(ASTM D2216), grain size (ASTM D422), specific gravity (ASTM D854), and Atterberg limits (ASTM D4318 wet multipoint procedure). Geotechnical technicians at GSO's Marine Geomechanics Laboratory (MGL) conducted shear strength analyses on split cores. The MGL also conducted consolidation and permeability analyses not reported here.

RESULTS AND DISCUSSION

SEDIMENT PROPERTIES OF THE MYSTIC RIVER AS COMPARED TO DREDGED SEDIMENTS

The sediments collected from the Mystic River (MR) near the area that was dredged consisted primarily of very dark gray to black silty clay, with a minor amount of sand (<10%). The sediments displayed high water content, ranging from 82-212% (average 143%). The material commonly had a "bubbly" appearance, consistent with the lack of P-wave data, suggesting the presence of gas (methane) within the upper sediments. Log data showed that the sediments did have internal stratigraphic structure.

One of the goals of the geotechnical investigations was to evaluate how the process of dredging changes the engineering characteristics of sediments. Hydraulic dredging has been found to remold the sediment, thereby changing the geotechnical properties from the original *in situ* values (Poindexter Rollings 1990). Although the BHNIP dredged material was removed using mechanical methods (closed clamshell), the dredging process appeared to have altered the sediment's inherent strength characteristics. Atterberg limits data for the MR sediments, along with data from the barge, T_0 , T_1 and Postcap surveys, were compiled into Casagrande's plasticity chart that shows the relationship between the liquid limit and plasticity index relative to standard soil classifications (Figure 1). The plasticity chart provides an indication of the physical state of saturated sediment, ranging from plastic to liquid states as a function of the natural water content.

Most of the samples collected from this project represent inorganic clays of high plasticity. However, the samples collected from the MR cores displayed liquid limit values (LL) of >100% and

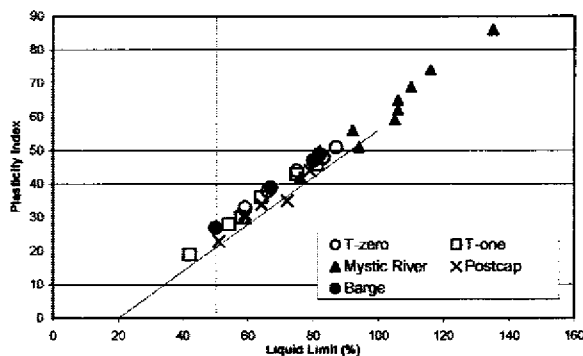


Figure 1. Plasticity chart for five survey stages, showing the Atterberg limit data relative to the "A-line" soil classifications.

plasticity index (PI) values of >50 , while almost all of the samples collected from both the barge and cell M2 were less than 100% LL and 50% PI (Figure 1). All barge samples fell in the range of the cell M2 survey data and outside of the range of MR Atterberg limits.

The decrease in liquid limits of the MR sediments after dredging (barge samples) may be indicative of a) differences in the sediments dredged versus those closely adjacent that were sampled for the determination of *in situ* conditions; or b) loss of some fine-grained sediment during the dredging process. Because the water content was relatively unchanged, the reduction in bearing strength (PI) may be the result of a disturbance of the fabric of the *in situ* sediment during dredging. Shear strength data were consistent with this observation: the shear strength of the upper 50 cm of cores between the MR and T_0 surveys decreased from an average of 1.8 kPa to 0.4 kPa (excluding all data from BBC).

Other than a change in Atterberg limits and shear strength, there were no other statistically significant changes in physical properties between the MR and the T_0 surveys. The average grain-size distribution was almost identical between the two surveys. Within each core, water content tended to decrease with depth; however data showed high variability, especially for the MR sediments. Because of the dependence of water content with depth in the cores, the average water content was compared for the upper 50 cm of cores collected during MR and T_0 surveys. The average water content for the upper 50 cm of the MR and T_0 survey cores was essentially identical (152%, 148%, respectively). The water content of the grab samples

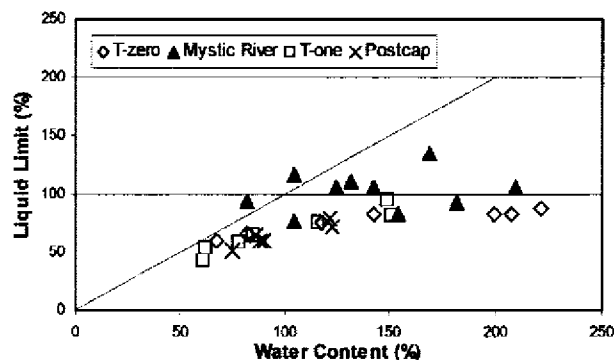


Figure 2. Liquid limit vs. water content for Mystic River and M2 sediments.

(sediment-water interface to a penetration depth of 25 cm) was higher, but still similar for the two surveys (182%, 209%, respectively).

If the natural water content of sediment is above or close to the liquid limit, the sediment may exhibit "sensitive" characteristics, which suggests that the sediment will lose strength when disturbed. Discrete water content measurements were compared with the liquid limit data collected at the same depth intervals for the individual surveys (Figure 2). The number of paired water content/liquid limit samples was limited, but the data do suggest that the MR sediments, both before and after being dredged, had low bearing strength and potentially would not be readily capped. Nearly one meter of sand was present above the dredged material in most of the postcap cores, suggesting that there are other factors that may be important in determining the potential for a cap to be placed on sediments.

SHEAR STRENGTH ANALYSIS

One of the major elements that controls the construction of a successful cap is that the shear stress along the interface between the cap and underlying sediments must not exceed the strength of the dredged material (Bokuniewicz and Liu, 1981). Shear strength is the maximum force that can be mobilized within a soil mass to resist shear deformation. Shear strength increases in consolidated sediment, and generally increases with depth in the sediment. Lengthening the time allowed for consolidation of the dredged material prior to capping should theoretically increase the shear strength of the sediment. The strength of the

deposit will further increase under the weight of an overburden, *i.e.*, the cap. Because of the importance of the strength element in the assessment of the engineering properties of the dredged material, shear strength of the cored sediments recovered in different stages of the geotechnical investigations was evaluated more closely.

Shear strength measurements were plotted as a function of depth in the sediment cores for T_0 , T_1 and Postcap surveys. Shear strength values from BBC and sand cap were excluded from this analysis. The data showed a rapid increase of shear strength in the upper 1 meter of the cores for the T_0 and T_1 surveys. Part of this increase may be an artifact of coring, as the sediment consolidates more rapidly in the core liner and an increase in strength of the sediments at the bottom of the core is expected.

Most notable was the increase of shear strength in the sediments immediately below the cap. In fact, the shear strengths are higher in the top meter as compared to the sediments deeper in the postcap cores, suggesting that the placement of the cap caused the surface sediments to consolidate, but the deposit has not reached equilibrium relative to a standard strength profile. The sediments in the upper meter of both the T_0 and T_1 surveys had low shear strengths of <1 kPa, indicating very low strength in all of the precap sediments.

In order to statistically evaluate the shear strength data from different survey stages, data from the upper 100 cm of each core were compiled, excluding samples from BBC and sand cap. Samples from the upper meter of fine-grained sediment below the cap were evaluated for the postcap data. The shear strength decreased from the Mystic River (MR) sediments to being placed in cell M2. Both the T_0 and T_1 sediments had very similar shear strength properties, and increased with placement of the cap to values more similar to the MR sediments. These data would suggest that the capping process itself was much more effective in increasing the bearing strength of the sediments as compared to self-weight consolidation. There were outliers in the data for the T_0 and T_1 stages indicative of increased heterogeneity of the precapped sediments. The very low shear strength of these sediments increases the uncertainty of the actual bearing strength. Although the viscometer used for the soft material had a very high sensitivity (0.03

kPa), some caution is warranted about evaluating the strength characteristics of this material, especially between the two precap surveys. The coring process can also serve to alter the *in situ* shear strength.

DIAGNOSTIC MEASUREMENTS TO DETERMINE CAP READINESS

One of the goals of this study was to determine the material properties that would allow predictive modeling of consolidation and sediment strength to be used in future projects. The cap at cell M2 was composed of up to a meter of tan to gray and black sand overlying the dredged material in five of six cores collected. The homogeneity of the sand was apparent in the bulk density log data, showing the higher bulk density of the sand cap (approximately 2.0 g/cc) overlying the dredged material (approximately 1.5 g/cc; Figure 3). The log data showed an increase of bulk density with depth in the sediments below the cap, suggestive of a normal pattern of consolidation. The one exception was core M2-4, which had no evidence of sand throughout the entire core. The physical parameters of this core were extremely uniform all the way down the core, including no apparent increase of bulk density to the bottom of the core (Figure 3).

The geotechnical data collected during the various stages of the cell M2 project challenged the typical process of evaluating capping effectiveness. First, the only clear diagnostic change of properties between the T_0 and T_1 surveys was in the water content of the surface sediments. The average water content of the surface sediment as collected by the grab samples decreased between the two surveys, from 209% to 165%. The average water content in the upper 50 cm of the cores collected during the two surveys was similar, at approximately 100%. Comparing the core and grab sample data suggests that changes in the upper sediment column may be the most important to verify when evaluating cap-readiness. The water content data support the field observations conducted by GLDD and the visual description of T_0 and T_1 cores.

Other than the water content of the surface grabs, no clear, statistically significant changes in the physical parameters measured would suggest the CAD sediments were ready to be capped, and yet most of the sediments in this cell were success-

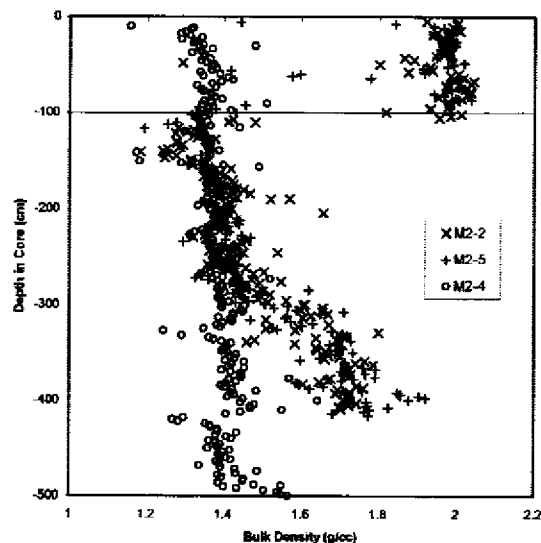


Figure 3. Logged bulk density data from selected postcap cores.

fully covered with relatively clean cap material. The presence of the single core with no sand suggests that the mechanisms of settlement and stability of the dredged material and cap deposit is more complex than implied by an evaluation of sediment properties.

After cap deposition at cell M2, the sediments consolidated more rapidly than under self-weight conditions, as shown by the lack of topographic change in the multibeam bathymetry with the increase in cell material volume due to cap placement. The increase of shear strength of the fine-grained sediments below the cap was consistent with consolidation models that predict rapid consolidation of sediments under loaded conditions (e.g., Silva *et al.*, 1994; Poindexter Rollings 1990). The process of consolidation requires an expulsion of pore water that may cause layers to deform. In the case of the BHNIP, and the impermeability of BBC, the expelled pore water was restricted to movement up through the cap. The recovery of core M2-4 with no sand suggests that pore water expulsion, and the resulting release of excess pore pressure, was potentially focused in destabilized areas of the cap. When mud is overpressured in areas with rapid sedimentation (*i.e.*, deltas), structures called diapirs can form as “mud vents” through overlying sediments that serve to reduce excess pore pressure. This diapiric process has been suggested as a mechanism for the presence of fine-grained sediments that were above the caps in

the earlier cells (SAIC, 1999). Subbottom data collected from cell M2 showed potential diapir-like structures through the cap. Additionally, the presence of these diapirs is confirmed by the physical properties displayed in core M2-4, which showed that the sediment physical properties were relatively constant with depth.

Thus, the ability to predict and evaluate the efficacy of capping in a confined environment depends not only on accurate geotechnical measurements of the dredged and cap material, but also requires thorough understanding of the geotechnical framework of the disposal site. In the case of the BHNIP, the cells were constructed in essentially impermeable BBC, providing potentially the most important variable for capping success. The BBC walls and base of the containment cells did not accept the extruded pore waters that may have been readily accepted by a more porous material (*i.e.* sand, gravel). As a result, the expulsion of pore water was restricted to upward flow into the sand cap. The downward force exerted by the sand cap pressurized the underlying, fluidized dredged material. Diapir formation occurred when the upward pressure of the dredged material pore water exceeded the shear strength of the sand cap, allowing a surface vent to form.

From an operational viewpoint, the increase in consolidation time empirically improved the level of success of capping, although no quantitative relationship could be found to verify this except for the decrease in water content of the surface grabs between the two precap surveys. Shear strength measurements provided the clearest indication of the increased “cappability” of the sediments, although this increase only occurred after cap material was placed.

In the broader view, evaluation of the relative success of a capping project needs to be measured against the overall environmental goals of a project. In the case of the BHNIP, the sand cap in cell M2 was determined to be providing a practical physical barrier above the majority of the underlying dredged sediments. If additional protection was required for a project, a phased capping approach should be considered, as the process of capping serves as the best mechanism to stabilize the underlying sediments.

CONCLUSIONS

The natural cohesion and strength of the Mystic River sediments were altered by the dredging process, resulting in sediments in the CAD cell that were unstable due to high water content and low shear strength. During the 5-month consolidation time between the T_0 and T_1 surveys, the change in water content of the surface sediments (as collected in the grab samples) was the geotechnical measurement that provided the clearest indicator of "capreadiness."

The most statistically significant change of physical properties of all the cell M2 surveys was the increased shear strength of the sediments after capping. Capping-induced consolidation resulted in sediments of strength similar to *in situ* (MR) material, suggesting that pre-capping might be a useful operational approach for future projects.

The results from Core M2-4 suggested that excess pore water was released not only through the cap but also vented through diapir structures that served to breach the caps in discrete areas.

Future projects should include an evaluation of the geological environment that is under consideration for a CAD project, such as an evaluation of the *in situ* strength of the material to be capped and the porosity and permeability of the CAD cell sediments; consideration of innovative capping approaches, including a phased capping approach, should also be considered.

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Core Analysis: Is it a Good Indicator of Metal Release and Capping Efficiency?

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ABSTRACT: Analysis of core samples is commonly used to evaluate contaminant transport from capped sediments. This paper evaluates the effectiveness of the core analysis technique as an indicator of metal release and capping efficiency. Six columns were set up in the laboratory to simulate metal release from capped contaminated sediment under conditions of submarine groundwater discharge. Metal concentration gradients in capped sediment or capping material were not statistically different from zero for all the core samples collected from the columns. Results indicate that metal concentration gradients in the sediment or capping material may not be good indicators of metal transport under conditions of advective flow.

Key words: sediment, capping, core analysis, metals

INTRODUCTION

Monitoring capping stability and retardation of contaminants after capping operations is very important to insure isolation of contaminants from aquatic environments. Core analysis commonly has been used in the field to evaluate capping efficiency and stability based on visual inspection and chemical analysis of sectioned segments. A number of studies on the stability of capped dredged material report a distinct interface between the capping material and the contaminated sediment. This has led to an assessment of good stability and efficiency in retarding contaminants based on contaminant distribution in the core or bulk sediment (see Table 1 for a summary of selected field capping efficiency studies). Results of core analysis have been used to determine chemical gradients as indicators of chemical transport (Fredette *et al.*,

1992), to analyze chemical concentration change over time (Brannon *et al.*, 1990), and to compare contaminant concentrations in the capping material and sediment to the original material, reference areas, or regional areas (Murray, 1994). Most studies using core analysis assume that measurable chemical gradients of contaminant concentrations are effective indicators of chemical migration. This is based upon the hypothesis that molecular diffusion is the major transport mechanism in the sediment. However, advection caused by tides, storms, consolidation, bioturbation, anthropogenic activities and Submarine Groundwater Discharge (SGD) into the cap is always possible, and would result in much faster contaminant transport (USEPA, 1998). In the cases where advective flow dominates, concentration gradient is less likely to occur.

The objective of this study was to evaluate the core analysis technique in detecting metal release and capping efficiency under conditions of continuous advective flow. Metals including Ni, Cr, Cu, Zn, Mo, Cd, Pb, and Mn were studied.

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Table 1. A summary of selected field capping efficiency studies.

Reference	Capping Site	Time after capping	Main Technique	Results	Conclusions
Fredette <i>et al.</i> , 1992	Long Island Sound, USA	7 and 11 years	Core analysis	No obvious chemical gradients, most cores observed distinct interface	absence of physical or chemical disturbance
Murray, 1994	Massachusetts Bay Disposal Site, USA	12 years	Grab sediment sample analysis	Concentrations of all trace metals were relatively low compared to reference areas and regional areas	No accumulation of trace metals at the site
SAIC, 1995	Stamford-New Haven disposal sites, USA	months	Grab sediment sample analysis	Cu concentration lowered after capping while began to increase 2 months after capping	Surficial mixing of cap sediments with ambient sediments and deposition of local-source silt onto the capped mound should result in the reestablishment of background contaminant concentrations
		11 years	Core sample analysis	Most of cores had visually and chemically distinct interface	Silt cap are just as effective at containing contaminants and may cause even less disturbance than sand caps deposited on silt
Bokuniewicz, 1989	New York Bight Mud Dumpsite, USA		Vibracoring sampling; grain size analysis	The sand-mud interface was distinct visually; the transition from sand to mud occurred over a distance of less than a few centimeters.	
Brannon <i>et al.</i> , 1990	Durhamish waterway sand-capped mounds, USA	0.5-18 months	Chemistry analysis of vertical cores	There was no statistical difference over time between contaminant concentrations in a particular depth segment in either the cap material or the dredged material. The dredged and cap materials formed a sharp, relatively unmixed interface.	Sediment sampling and analysis proved to be useful for assessing the possible movement of contaminants from the underlying material into the cap.
SAIC, 1996	Mill-Quinnipiac River Disposal Mound, USA	8-9 years	Core sample analysis	Normalizing the trace metal data to the percentage fine grain size reduced the variation between cores and showed a distinct pattern of increasing metals concentrations with depth.	Most of the MQR core samples could be remnant New Haven Harbor capping material.

METHODS AND MATERIALS

The experiment was designed to observe metal fluxes in relation to metal distribution in the core samples under different conditions of continuous advective flow. Details of the experiment are presented by the authors in Liu *et al.* (2001a, b). Basically, six columns were set up to model the following conditions: a control column, with De-Ionized (DI) water as simulated groundwater (DIWater); with acidified groundwater (Acidified); with increased sediment depth (Increased-Depth); with increased flow rate (High-flow); and with acidified groundwater, increased sediment depth, and increased flow rate (Combination). (See Table 2 for a general profile of the experimental conditions).

After equilibration, SGD flow was initiated and effluent water samples were collected. The water samples were filtered prior to analysis for dissolved metal concentrations. Three cores were collected from each column at the end of the experiment. One core from each column was sectioned at 1-cm interval, microwave digested, and analyzed.

Table 2. A general profile of the experimental conditions.

Core Name	Total Running Time (Days)	Overlying Water Depth (cm)	Depth of Sediment (cm)	pH of Ground-water	Pore Vol. (ml)	Ave. Flow Rate (ml/hr)	Total Vol. (ml)
Control	118	2.2	5	7	1626	10.75±0.04	27213
DIWater	198	1.5	5	6	1639	9.97±0.03	47841
Acidified	57	2.3	5	3	1639	10.24±0.06	13536
Increased Depth	118	3	8.2	7	2096	10.94±0.03	30564
High-flow	55	2.5	5	7	1619	22.69±0.28	29338
Combination	541	2.7	8.2	3	2057	24.57±0.65	10203

1. Data of only 19 days are used because the flow rate dramatically decreased after 19 days;

2. The number following ± gives the standard error.

DISCUSSION

Under conditions of SGD, metals will be transported from contaminated sediment to the overlying water by the bulk flow. Thus, unless the groundwater flow is extremely slow, no significant concentration

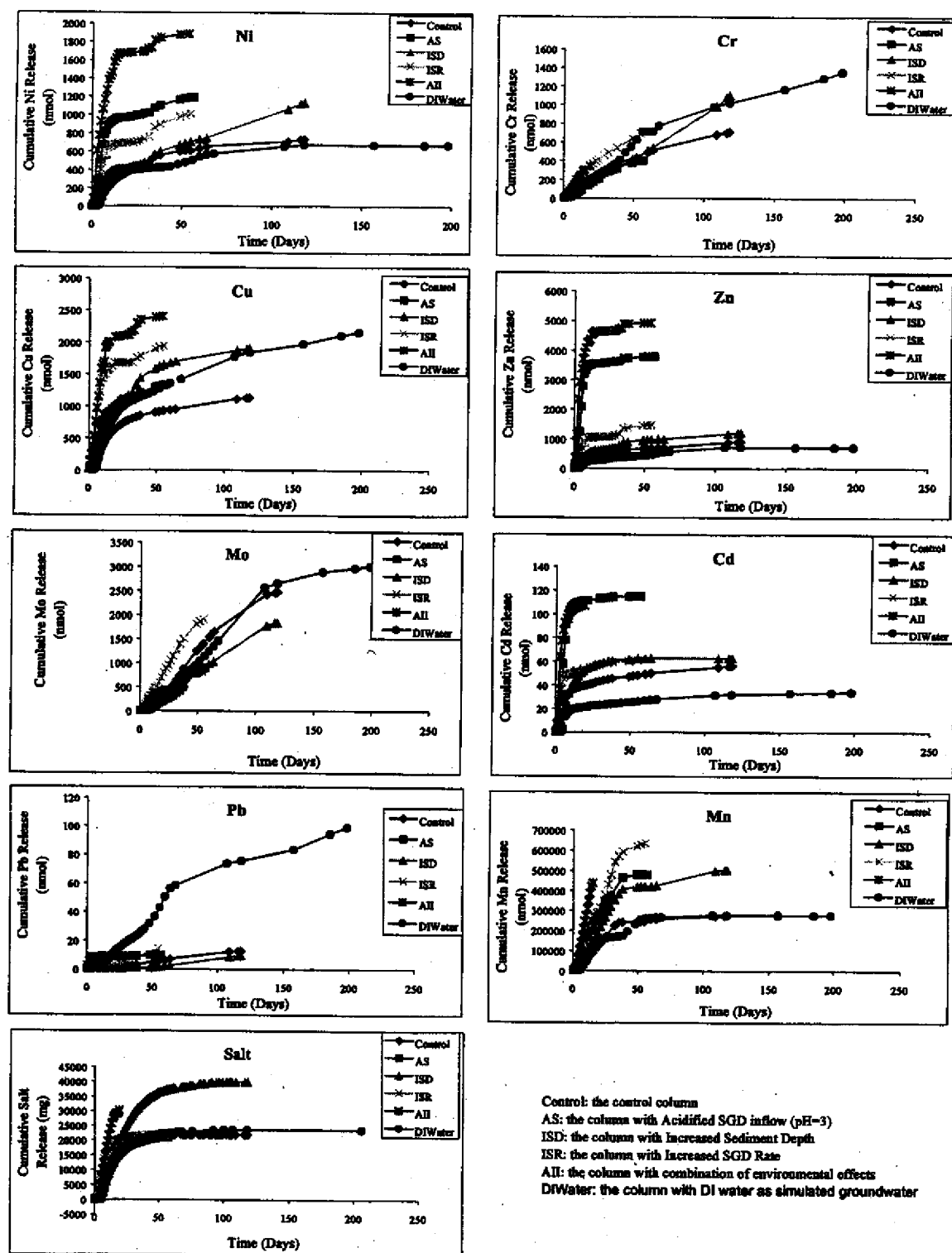


Figure 1. Cumulative metal release versus Time (Days).

Table 3. Flux estimation from molecular diffusion, and comparison with flux measurement. (nmol/m²/day).

	Estimated molecular diffusion flux	Measured flux
Cu (Combination)	14	7817±574 (3-10)* 2426±760 (10-19)
Zn (Combination)	14	35439±3235 (0-4) 9823±4510 (4-9) 2091±1210 (9-19)
Cd (Acidified)	0.1	694±54 (3-8) 8.2±3.9 (8-57)
Cd (Combination)	0.08	1224±119 (0-3) 323±119 (3-7) 37±15 (7-19)

*: Time (Day);

The number following ± gives the 95% confidence interval.

gradient in the pore water would be expected after contaminant breakthrough. Under conditions of simulated groundwater inflow, the results suggest that there was no significant metal concentration gradient in the capping material. However, metal fluxes to the overlying water were significantly greater than zero and could potentially exert ecological effects. For selected metals, the estimated molecular diffusion fluxes based upon concentration gradient in the capping material were much smaller than the measured fluxes (Table 3). In addition, Figure 1 suggests that metal fluxes changed during the course of the experiment. High initial fluxes occurred from capped sediment in both the presence and absence of simulated groundwater discharge, which might have been caused by consolidation (Liu *et al.*, 2001a). Metal concentration gradients in core samples collected at specific times are unable to detect flux changes through time. Results from the experiment suggest that metal concentration gradients in the capping material may not be a good indicator of metal transport under conditions of groundwater inflow.

In most cases, metal concentrations in the contaminated sediment were not significantly different from the original concentrations in the sediment. This suggests that changes in metal concentration may not be a good indicator of metal loss. An estimate of detectable loss from sediment would be 80, 400, 600, 700, 10, 3.5, 100, 500 mmol for Ni, Cr, Cu, Zn, Mo, Cd, Pb, and Mn, respectively using the current sediment analysis technique. Figure 1 shows that cumulative metal release is much less than the detectable loss from sediment analysis. Although significant metal loss was detected for Cr and Zn for the Acidified core, metal release from the column was not as high as would be expected from sediment loss. Adsorption capacity of capping material played an essential role in these cases. Thus, decreases in metal concentrations in sediment do not necessarily indicate a high release of metals.

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Evaluation of Five Capped Aquatic Disposal Cells in Portland, Oregon

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ABSTRACT: During the 1990s, the Port of Portland, Oregon, disposed of dredged material in five capped aquatic disposal (CAD) cells within Ross Island Lagoon, an active aggregate mining facility in the Willamette River at Portland, Oregon. The cells contain between a few thousand and nearly 100,000 cubic yards of contaminated sediments. Regulatory and public interest led the Port to evaluate the cells in late 1999 and early 2000 to address questions of human and environmental health and safety. The investigation focused on establishing fundamental physical, chemical, and biological parameters for the CAD cells. In addition, potential human health and environmental exposure pathways were carefully modeled to evaluate risk. Several innovative investigation techniques, including deployment of flux chambers and in-water piezometers, were employed to evaluate contaminant mobility.

Results of the site investigation were made public in mid-2000. Conclusions indicate that the CAD cells are functioning as expected and are safe, excepting a slope stability issue unrelated to the Port disposals. This presentation provides an overview of the engineering attributes of the five CAD cells, the innovative investigation techniques, and conclusions as to human health and environmental risks. These observations may have applicability to engineering design, construction, and monitoring of CAD sites in other regions.

Key words: sediment assessment, CAD, capping, Ross Island Lagoon, Portland, OR

BACKGROUND AND INVESTIGATION ELEMENTS

Ross Island Lagoon is situated in the Willamette River at Portland, Oregon. The lagoon was created in the late 1920s, when Ross and Hardtack Islands were joined with an earthen dike that closed a former channel in the Willamette River. The lagoon is mined for sand and gravel by Ross Island Sand and Gravel (RIS&G), the owner and operator. Pursuant to an approved reclamation plan, portions of the mining area are being reclaimed by RIS&G with fill material. Since 1982, more than 6 million cubic yards (cy) of fill from multiple sources have been placed at the site as part of upland and in-water reclamation, including 160,000 cy of Port of Portland (Port) dredged material placed in capped aquatic disposal

(CAD) cells.

In the fall of 1997, increased public awareness of disposal practices at the RIS&G facility prompted the Governor's Office to request an environmental investigation of the site. In response, the Port implemented the current investigation to evaluate environmental quality issues related to the Port confined dredged material. In this discussion, Port dredged material refers to the material before it was placed in the containment cells; Port confined dredged material refers to the material after it was placed in the containment cells; and non-Port fill refers to fill material from sources other than the Port.

DISPOSAL OF PORT DREDGED MATERIAL

In five events between 1992 and 1998, the Port transported approximately 160,000 cy of

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dredged material derived from maintenance and remedial dredging to Ross Island Lagoon for permitted confined disposal. Under contract with the Port, RIS&G accepted, placed, and capped the Port's dredged material in five in-water containment cells located in the reclamation area at southern end of the lagoon. Cells 1 through 4 were created by excavating older, non-Port fill or other materials using clamshell dredge mining methods. Cell 5 was created using an existing depression in non-Port fill. Following disposal of the Port's dredged material from either a bottom-dump barge or tremie tube, each cell was capped with a confining layer of fine-grained material derived from on-site sand and gravel washing and processing. Individual disposal volumes ranged from about 3,200 cy to about 95,000 cy. The Port dredged material typically consisted of fine-grained sand and silt.

Placement of the Port dredged material was reviewed by and conducted with the approval of state and federal authorities, including the U.S. Environmental Protection Agency (EPA), the U.S. Army Corp of Engineers (Corps), and the Oregon Department of Environmental Quality (DEQ). The cell caps were placed to physically cover the Port dredged material, and the Port and permitting agencies expected that subsequent in-water reclamation filling above the caps would further isolate the Port confined dredged material.

FIELD STUDIES AND LABORATORY TESTING

For the current investigation, the Port conducted an extensive field exploration program to collect groundwater, surface water, and sediment samples characterizing the ambient physical and environmental conditions at Ross Island. Nearly 2,500 feet of drilling were completed in the lagoon and upland locations so that subsurface sediment, soil, and groundwater conditions could be observed. Over 500 samples were obtained for visual observation, physical properties testing, and chemical analyses. Selected lagoon borings were converted to piezometers, and upland borings were converted to groundwater monitoring wells for water quality sampling and evaluation of groundwater flow and gradients. Groundwater was also sampled from flux chamber seepage meters deployed at the lagoon mudline above three of the disposal cells.

In addition, samples of lagoon surface sediment were collected for physical, chemical, and biological testing. Surface water samples were also collected from Ross Island Lagoon and the Willamette River. In all, nearly 90 samples of soil, sediment, and groundwater were submitted for laboratory chemical analysis.

TECHNICAL ANALYSES AND MODELING STUDIES

Results from field exploration and laboratory testing yielded data for several technical analyses that evaluated the potential for chemical constituents in Port confined dredged material to be released to the environment. These analyses included:

- Groundwater flow and gradient characterization;
- Contaminant mobility (groundwater fate and transport modeling);
- Geotechnical stability modeling;
- Sediment quality characterization;
- Lagoon bathymetry analysis (past, present, and future conditions); and
- Disposal processes (particulate and dissolved masses released to the water column).

Several of these analyses involved the use of computer models to simulate groundwater flow and contaminant transport, slope stability, and disposal processes. Key conclusions of these analyses are presented below as they relate to potential contaminant migration pathways from the Port confined dredged material.

CONCEPTUAL SITE MODEL

The conceptual site model considered several elements to characterize the site and Port confined dredged material:

- The physical and hydrogeological setting of Ross Island and the containment cells;
- The distribution of chemical constituents in Ross Island Lagoon; and
- Human and ecological receptors.

PHYSICAL SETTING

The lagoon is enclosed except for an approximately 500-foot-wide outlet to Holgate Slough on the northeast side. Upland areas of Ross and

Hardtack Islands are generally tree covered, excepting the area of the RIS&G materials processing plant. Ongoing dredging by RIS&G has expanded the lagoon to an area of about 140 acres, with mining currently focused in the central and northern areas of the lagoon. In-water reclamation filling at the southern end of the lagoon has created a relatively shallow bench with a water depth of about 20 feet. The remainder of the lagoon ranges up to about 130 feet in depth. The narrow entrance and limited surface water exchange with the river tend to minimize circulation within the lagoon.

Because of its location, Ross Island Lagoon is affected by the hydraulic characteristics of the Willamette River. Daily tidal variations produce river elevation changes of about 1 to 3 feet near Ross Island. Seasonal flooding can cause short-term water level changes of 10 feet or more. Upstream storage reservoirs in the Willamette Basin stabilize flows during flood-prone winter months and dry summer months. Although flooding has historically overtopped upland areas at Ross Island, there is no indication that flooding has promoted, or will promote in the future, erosion that would threaten the integrity of the containment cells.

SITE HYDROGEOLOGICAL SETTING

Fill of various origins and unconsolidated alluvial sands and gravels overlie older cemented sedimentary rocks of the Troutdale Formation in the vicinity of Ross Island. The containment cells were capped with fine sands and silts from on-site sand and gravel processing, and additional non-Port fill was placed over the capping materials. The Port confined dredged material and non-Port fill, which are generally fine-grained and visually similar, were identified with the aid of survey data gathered before and after the dredged material and capping materials were placed.

Groundwater piezometers were installed in Port confined dredge material in four of the containment cells, and deeper piezometers were installed in native alluvium beneath two of the cells. Permanent groundwater well clusters were established at three upland locations. During drilling, groundwater was continuously encountered from the lagoon mudline down to the Troutdale Formation. In the upland wells,

groundwater was present from about 10 to 20 feet below ground surface down to the Troutdale Formation.

Groundwater elevation data obtained from the piezometers and wells during a tidal study showed that an upward vertical groundwater gradient is present from the Troutdale Formation and native alluvium into lagoon fill materials and the surface waters of Ross Island Lagoon. Groundwater seepage rates into the lagoon are relatively low because of small differences in groundwater elevations between the lagoon and underlying groundwater.

SEDIMENT CHEMISTRY

Surface sediment chemistry results indicated that the chemical quality of the lagoon is good relative to applicable risk-based sediment quality screening criteria. Although chemical concentrations exceeded screening criteria in localized areas, there is no indication of widespread contamination. Constituents that exceeded criteria (*e.g.*, PCBs, mercury) are routinely found in industrial areas and are not unique to the Port confined dredged material. Subsurface chemical concentrations in samples of Port confined dredged material were comparable to, or slightly lower than, average concentrations of the same constituents in historical pre-dredge samples. These results made it possible to readily distinguish Port confined dredged material from non-Port fill and overlying capping materials.

POTENTIAL HUMAN AND ECOLOGICAL RECEPTORS

Ecological surveys reveal significant diversity of wildlife and vegetation in upland areas. The terrestrial environment provides nesting habitat for ecologically important bird species such as Great Blue Herons and American Bald Eagles. In contrast, the abundance of benthic organisms and non-migratory fish species in Ross Island Lagoon is low, with correspondingly limited habitat quality as compared to other freshwater environments. This finding is consistent with the active industrial nature of Ross Island Lagoon. Although Ross Island Lagoon is identified as critical habitat for Chinook salmon and other salmonids listed as threatened or endangered under federal and state designations, migratory salmonid species present in the lagoon during surveys conducted in 1999

represent a small fraction of the total population in the lower Willamette River system. Moreover, exposure time for anadromous species is likely to be limited in duration.

Beneficial use surveys verified that established industrial, commercial, and residential land uses near Ross Island are likely to continue. Recreational uses in the vicinity include wildlife viewing, hiking, boating, fishing, and other water-dependent activities. Although not encouraged, some recreational use of the lagoon and uplands will likely continue. Groundwater and surface water are not currently used for drinking and are not likely to be in the future.

CONTAMINANT TRANSPORT PATHWAYS

Three general contaminant transport pathways were identified for the Port confined dredged material:

- Groundwater transport of chemical constituents from the containment cells to surface water or groundwater;
- Physical disturbance of the containment cells from natural erosion or human influence; and
- Particulate and dissolved mass dispersal to the water column during placement of the Port dredged material.

GROUNDWATER TRANSPORT FROM CONTAINMENT CELLS

This pathway is associated with the potential migration of chemical constituents from the containment cells via groundwater. The surface water of Ross Island Lagoon is a potential receptor. Upward groundwater flow directions indicate that transport pathways to deeper groundwater and the Willamette River are not present.

As recommended by the Corps for freshwater environments, Sequential Batch Leaching Tests (SBLTs) were performed to evaluate the potential for chemical constituents in the Port confined dredged material to leach into containment cell pore water. Data from the SBLTs and the piezometer groundwater samples were employed to simulate groundwater transport and contaminant migration using the MODFLOW and MT3DMS computer codes.

Predicted post-reclamation concentrations of chemical constituents in groundwater discharging

from Port confined dredge material to the lagoon are below screening criteria, with limited exceptions for arsenic and lead. At two cells, arsenic concentrations in groundwater are predicted to exceed regional background levels for surface water in the Willamette Basin over 100 to 1,000 years. However, conservative modeling assumptions likely overestimate the predicted concentrations, which are in any case below risk-based screening criteria in recent EPA Region 6 guidance regarding fish consumption by humans. Further, locally higher arsenic concentrations may result from naturally occurring minerals.

PHYSICAL DISTURBANCE TO CONTAINMENT CELLS

Potential physical disturbances include human activities and natural causes such as river flooding that could affect the integrity of the in-water containment cells, caps, or non-Port fill adjacent to the cells. Slope stability issues arose from mining by RIS&G between 1992 and 1998 that removed material providing lateral support to three cells. Slope stability issues were evaluated using the SLOPE/W geotechnical computer model to simulate current and post-reclamation conditions. SLOPE/W, a standard engineering code, calculates a factor of safety for potential failure surfaces and has particular application to underwater structures.

Modeling results indicated that the potential exists for deep-seated slope failures along the edge of the fill bench at the southern end of the lagoon that could disturb three containment cells. Such disturbance could result in the exposure and resuspension of Port confined dredged material. Potential slope failure risk is greater under seismic loading. In addition, geotechnical modeling and upland drilling indicated that the dike area is not susceptible to erosion or breaching from flooding, and the dike is expected to be stable under static and seismic loading.

PARTICULATE AND DISSOLVED CONSTITUENTS DISPERSED DURING DISPOSAL

During the placement of Port dredged material, a small percentage of particulate material was dispersed beyond the disposal and capping areas as the Port dredged material fell through the water

column. The expected mass was estimated for each disposal using the Short-Term Fate of Dredged Material Disposal in Open Water (STFATE) computer program. Chemical constituents were also present in pore water released to the lagoon as the Port dredged material fell through the water column and then settled in the containment cells. Laboratory consolidation modeling was used to estimate the volume of pore water expelled as the Port dredged material accumulated.

Short-term impacts to water quality during dredged material placement were of limited duration, and permitted, subject to monitoring and best management practices. Port disposal events completed using bottom-dump barges dispersed about 5 percent of the total mass of dredged material beyond the cell boundary. For disposal using a tremie pipe, less than 1 percent of the material was dispersed outside the cap boundaries. These dispersal predictions may overestimate the case, however, because the calculated capping areas were conservatively small as they were defined using bathymetric measurements, rather than model predictions.

Particulate material dispersed beyond the cell capping boundaries has been buried by 2 feet or more of subsequent non-Port fill, excepting in one limited area where bathymetric data indicate that dispersed material could remain within the top 1 to 2 feet below the existing lagoon mudline. Although several surface sediment samples from that limited area failed bioassay testing, elevated pH and ammonia unrelated to the Port confined dredged material may be the cause. In any case, the potential contribution of constituents in the dispersed particulates from Port dredged material could not account for observed bioassay testing failures.

As occurs at all CAD sites, pore water was released during disposal as Port dredged material fell through the water column and consolidated within the containment cells. Recent water quality data do not indicate any water quality impacts or risks to surface waters of the lagoon from this potential pathway.

CONCLUSIONS

No current or future unacceptable human health or environmental risks related to groundwater transport of chemical constituents in Port confined dredged material were identified.

Groundwater flow is upward toward the lagoon, which eliminates the potential transport of contaminants to deeper groundwater and the Willamette River. The predicted concentrations of Port-related chemical constituents reaching surface sediments and surface waters of Ross Island Lagoon are below corresponding risk-based screening criteria and regional background levels.

A geotechnical evaluation indicates that in-water fill slopes adjacent to three containment cells are at risk of failing. The current slope configuration results from mining that removed lateral support to the containment cells. Slope failures could result in the exposure and resuspension of Port confined dredged material. These risks increase during a design seismic event. Recently, DEQ has confirmed these findings and prioritized placement of reclamation fill to buttress the at-risk slopes.

As expected during disposal of the Port dredged material, some particulate material was dispersed to the water column. The dispersed material was later covered with capping material and/or non-Port fill. No current or future unacceptable human health or environmental risks were identified in relation to the disposal and placement process.

Construction, configuration, and capping of the containment cells in Ross Island Lagoon were consistent with existing regulatory guidance on capped aquatic disposal. Extensive physical and chemical data demonstrate that the containment cells continue to safely isolate the Port confined dredged material from the environment. The cells are functioning as intended.

Operating and Managing the Newark Bay Confined Disposal Facility

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ABSTRACT: The Port Authority of New York and New Jersey constructed and has operated a subaqueous confined disposal facility at Port Newark, New Jersey since November of 1997. The Newark Bay Confined Disposal Facility (NBCDF) is a 1.5 million cubic yard subaqueous "pit" excavated from the bottom of Newark Bay. The NBCDF has served as a much-needed disposal site for dredged materials that are deemed unsuitable for placement at the federally designated Historic Area Remediation Site (HARS) off of Sandy Hook, New Jersey.

Malcolm Pirnie, Inc. was retained by the Port Authority to develop an Operations and Management Plan and implement the Plan. Over the past three years, eleven disposal projects have been successfully completed, and one is underway. Operation of the facility includes visual observation during every disposal event, periodic TSS water quality monitoring, and bathymetric surveying. Operational monitoring has shown that no release of sediments from the facility has occurred.

Key words: sediment, New York/New Jersey Harbor, bathymetry, CDF, subaqueous disposal, plume tracking, water quality monitoring, TSS monitoring

INTRODUCTION

The Newark Bay Confined Disposal Facility (NBCDF) is a disposal site for dredged materials that are deemed unsuitable for ocean disposal at the federally designated Historic Area Remediation Site (HARS) off of Sandy Hook, New Jersey. Dredged material to be placed in the NBCDF must originate from the New York/New Jersey Harbor in waters contiguous to the State of New Jersey including Newark Bay, the Arthur Kill, and the Kill Van Kull (collectively the "Draw Area"). The NBCDF is located just off the entrance to the Elizabeth Channel, New Jersey (Figure 1), and has been constructed and permitted

to receive approximately 1.5 million cubic yards of dredged material that is otherwise restricted from ocean disposal. Detailed information regarding operation, permits, and predisposal requirements for potential users is documented (Knoesel *et al.* 1998). The user fee for disposal is \$29 per cubic yard.

The NBCDF is located within a greater shallow water-depth area of Newark Bay, New Jersey. The NBCDF has an area of 26 acres at the water surface and was originally constructed to a depth of -70 MLW. Bathymetric surveys have indicated that in August 2000, the surface of the dredged material is at -35 to -40 MLW, or about 30 to 35 feet above the facility bottom. To date, over 900,000 cubic yards of dredged material have been disposed at the NBCDF, as calculated from

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pre- and post-dredging bathymetric surveys at the various dredging sites. This material has been deposited by over 400 scow loads from 12 different dredging projects/sites. The operation of the NBCDF is a great opportunity to learn how to effectively manage disposal in this way, and offers insight for designing and operating future sub-channel disposal facilities.

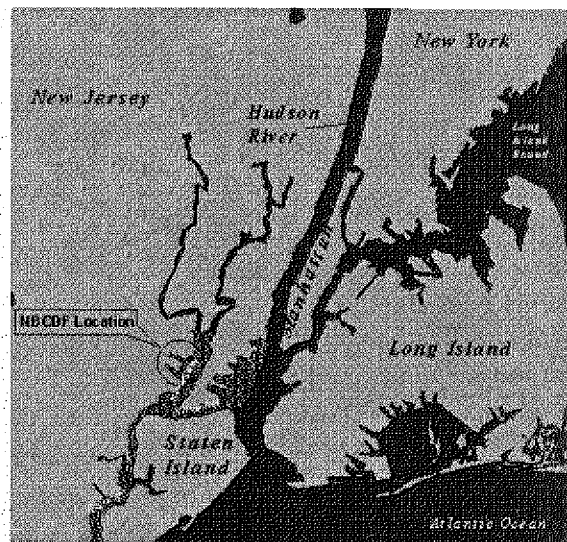


Figure 1. NBCDF location map and hatching showing the "Draw Area".

NBCDF MANAGEMENT

NBCDF is operated, managed, and monitored in strict accordance with permits and established procedures, as presented in the US Army Corps of Engineers (Corps) and New Jersey Department of The Port Authority of NY and NJ (PA) constructed the NBCDF in the summer and fall of 1997. The Environmental Protection (NJDEP) approved Operations and Management (O&M) Plan. Malcolm Pirnie, Inc., of White Plains, New York (Malcolm Pirnie), was retained by the PA to develop the O&M Plan and manage the NBCDF. Management includes disposal event oversight and the performance of periodic bathymetric surveys and water quality monitoring.

DISPOSAL OPERATIONS

Prior to disposal operations, the potential NBCDF User (User) submits to Malcolm Pirnie, Transportation and Disposal Plans, including

details of operations, points-of-contact, and equipment to be used. A Malcolm Pirnie "Field Professional" and a Corps Certified Dredge Inspector are present for all disposal operations. The Field Professional meets with the tugboat crew including the scowmen and reviews with them the procedures for using the NBCDF and protocols for radio communication. As new tug/scow personnel are added to the crew, similar meetings take place.

The Field Professional, in a separate motorboat, leads the tug/scow through the NBCDF entrance and proceeds to the location within the NBCDF where disposal is to take place. When the tug/scow is in a satisfactory position, the Field Professional instructs the tugboat Captain, "affirmative for disposal". If during a disposal event a malfunction occurs such that scow doors do not open or shut properly, the tug/scow remains inside the NBCDF until the malfunction is corrected. The User must also remove any floating debris.

FIELD MANAGEMENT ISSUES

As field placement activities have progressed, lessons learned have been incorporated into future disposal operations. This has helped to enhance safety and to ensure proper placement of dredged material. Primary lessons learned include:

- The need to orient the tug/scow into the wind during disposal to anticipate and minimize the affects of wind on the empty scow. An empty scow could easily get away from, or move the tug into the facility side slopes. It is also important to allow sufficient room for maneuvering the +200 ft scows inside the facility.
- Allowing proper slacking of tug/scow lines prior to opening scow doors, to avoid broken lines. During disposal the scow rises sharply due to reduced load. Should a scow break loose, it could impact the side slopes of the facility or float into the adjacent navigation channel(s).
- It is important for the Field Professional to maintain close communication with the tug/scow crew to confirm that all equipment is working properly. Although each scow is inspected by the scowman and a checklist filled out, malfunctions may occur. As required by the O&M Plan all malfunctioning scows must remain in the NBCDF until they

are fixed. In a few instances, the scow doors did not close immediately after disposal. The crews, working in close communication with the Field Professional, were able to quickly identify the problem and make the necessary adjustments to fully close the scow doors. In all cases, the scows were given permission to exit the facility.

WATER QUALITY MONITORING PROGRAM

To document that containment is effective and to confirm there are no impacts to the surrounding area, a Water Quality Monitoring program has been implemented. Total suspended solids (TSS) samples are collected beyond the NBCDF perimeter and in the entrance channel during and immediately after disposal events. In total ten disposal events are monitored for TSS for each 10 foot increment ("lift") of deposited material in the NBCDF.

SAMPLING PROGRAM

Water column samples are collected before and after selected monitored disposal events to assess TSS concentrations. Samples are collected at two stations downcurrent during each monitored event. Each station is located approximately 200 feet from the NBCDF boundary. An additional station located in the entrance channel is sampled to measure the "transit effect" of the scow/tug as they pass through the entrance channel. At each station, two samples are obtained: one shallow (from within six inches of the surface) and one deeper (at 20-foot depth or 18" from the bottom, whichever is shallower). Control samples at all stations are collected prior to each monitored disposal event.

RESULTS OF WATER QUALITY MONITORING

As of November 2000, thirty disposal events (over 3 lifts) have been monitored. For all disposal events, measured levels of TSS were consistent with control levels. The data collected is consistent with field observations that no plumes were visible outside the boundaries of the NBCDF during any of the monitored disposal events. Some turbidity is created by the "transit effect" as the tug/scow travels through the 20-foot deep entrance

channel or near the boundary of the facility; however, this turbidity is not associated with the disposal of dredged material and is of a short-term duration.

Figure 2 shows average values of TSS concentrations, for all monitored stations vs. time after disposal, for the 3 different lifts between November 1997 and October 1998. As shown in the figure, TSS levels from pre- and post-disposal samples do not vary significantly. The data points not connected to the lines represent TSS samples collected in the entrance channel prior to disposal, but immediately after the tug/scow passes through the entrance channel. These points have been labeled "transit effect." Data at -0.25 hours represents ambient conditions prior to the disposal event that occurs at time 0.00.

PLUME TRACKING

The O&M Plan requires Plume Tracking to be initiated if field observations indicate a TSS plume is present beyond the limits of the NBCDF. Plume tracking is to be conducted via transmissometer towed, at a depth of maximum turbidity, along lateral transects across the width of the plume. Although we have the ability to track plumes during monitoring, field observations have not indicated the presence of plumes from discharged sediments at the NBCDF. Therefore, plume tracking has not been necessary to date.

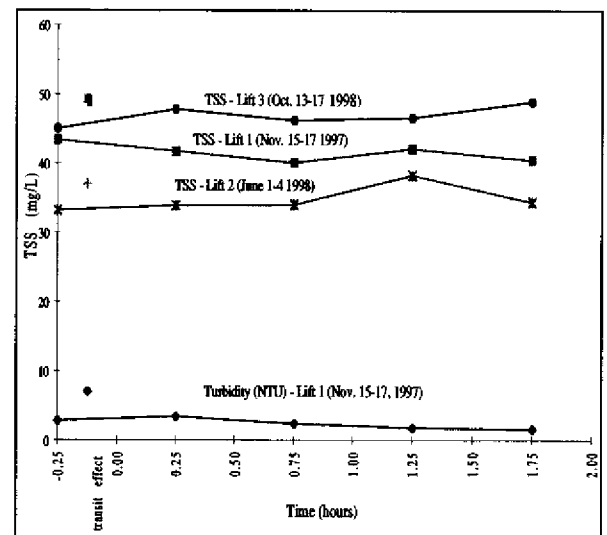


Figure 2. Water quality monitoring results.

BATHYMETRIC SURVEYING

The O&M Plan requires that bathymetric surveys be performed periodically within the confines of the NBCDF area and the entrance channel to monitor placement of dredged material. The surveys are conducted following each 10-foot lift of disposed material. We have also conducted additional bathymetric surveys and sediment sampling to determine how material behaves in the facility. Nine surveys have been conducted, consisting of data acquisition using a 200 kHz sounder along approximately 35 parallel tracklines spaced at 50-foot intervals. The horizontal positioning accuracy is ± 3 feet; depth sounding accuracy is ± 6 inches.

The electronic data set for each survey is used for volume computations to determine quantities of dredged material placed in the NBCDF.

Topographic maps with contour lines and 3-D perspectives have been created from these data. The surveys have shown that the deposited material is sufficiently fluid resulting in a fairly smooth, even layer of sediment on the bottom of the NBCDF (Figure 3). This has eliminated the need for varying disposal locations to allow for even distribution; therefore, we have been directing the tugs/scows to deposit material in the center of the NBCDF. Scows were directed to place at this location to keep debris in one area. The slope within the NBCDF is approximately 50:1.

HISTORY OF USAGE OF NEWARK BAY CDF

Figure 4 shows the historical usage of the NBCDF since operation began in November 1997. As of November 30, 2000, over 900,000 cubic yards of material has been dredged for disposal at the NBCDF. Usage of the NBCDF was most significant in the beginning of operations in November of 1997 and during the calendar year 1998. The NBCDF was a vital short-term solution to dredged material management crisis in the New York Harbor area, as evident by the usage rates in 1997 and 1998. In 1999 and 2000, the rate of usage decreased due to several factors including: (1) increase in the availability and decrease in the cost of upland disposal sites; and (2) emphasis on beneficial use of material in the New York Harbor area. Nevertheless, the NBCDF remains a viable alternative for disposal of dredged material unsuitable

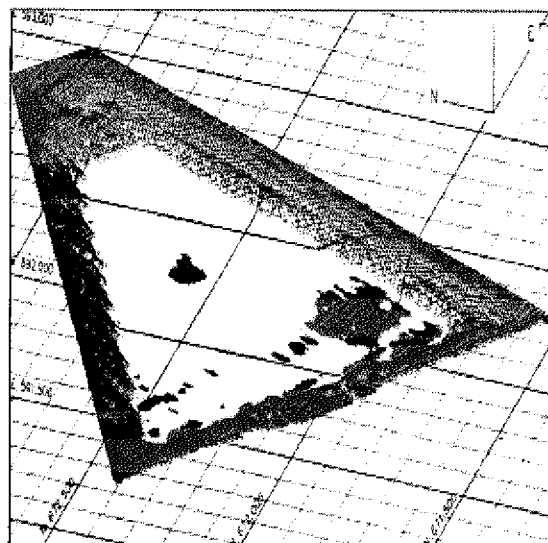


Figure 3. Bathymetric Survey 4, September 22-25, 1998.

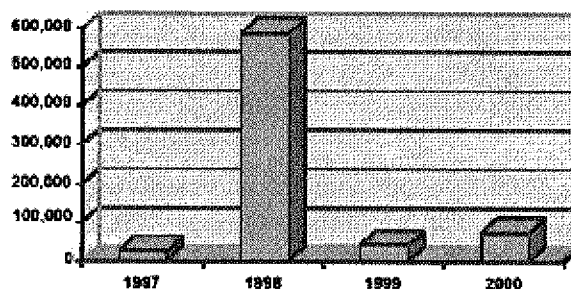


Figure 4. Summary of usage of NBCDF, volume in cubic yards.

for remediating the HARS.

CONCLUSION

All disposal operations at the NBCDF have been conducted in full accordance with the approved O&M plan and permit requirements. No releases of TSS were observed outside the boundaries of the NBCDF during or after any of the dredged material disposal operations. The NBCDF has proven to be an integral part of the overall strategy for managing the contaminated sediments in the New York/New Jersey Harbor. The success of the facility has proven that this method of disposal is effective and could be further developed to provide additional confined disposal facilities for the harbor.

Several factors have contributed to the success of operations:

- Conducting thorough predisposal meetings so

that the tugboat/scow personnel are familiar in advance with NBCDF protocol, especially regarding communication with the Field Professional. Good communications among all parties involved are essential.

- All parties are made aware of the need for safe/effective operations at the NBCDF. The future of more subaqueous disposal facilities in this area hinges on the safe and effective operation/management of this facility.
- The liquid properties of the deposited material resulted in a 50:1 slope, even layer of sediment on the bottom of the NBCDF. Scows have been directed to deposit the dredged material in the center of the facility, providing maximum room for maneuvering and minimizing distribution of debris so that sampling in the NBCDF can be performed more easily in the remainder of the site.
- Favorable disposal conditions. A majority of the projects to date have been conducted in relatively light winds with good visibility. The Field Professional has, albeit rarely, postponed a disposal event due to excessive winds or poor visibility. Also, wave action around the NBCDF is relatively small given the protected nature of Newark Bay.

The Newark Bay Confined Disposal Facility is a great success and guides the region if more subaqueous confined disposal facilities are desired in New York/New Jersey Harbor in the future.

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Biological and Chemical Analyses of Boston Harbor Confined Aquatic Disposal Cells

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ABSTRACT: This study investigated benthic biological and chemical characteristics to determine if confined aquatic disposal (CAD) cells constructed during the Boston Harbor Navigation Improvement Project (BHNIP) have resulted in changes to benthic conditions and communities. In April 1999, bottom sediments were sampled from the Phase I pilot cell (July 1997 construction), a Phase II cell (February 1999 construction), and from ambient sediments. Sediment profile images, water quality parameters, grain size distribution, invertebrate species composition and abundance, trace metals concentrations, and organic carbon concentrations were analyzed. The results of this study suggest that no major changes to the benthic habitat and community have resulted from the construction of the BHNIP CAD cells. Fine sediment fractions (72% to 98%) were consistently larger than sand fractions (2% to 32%) for all samples. Sediment profile images revealed shallow (< 3 cm) redox potential depths. Concentrations of trace metals appear to be similar among all stations. Invertebrate abundance was low at all stations (0.33-8.33 indiv./0.00196 m²), and only seven polychaete genera were found in total. Sand coverage and acoustic profile data from other studies reveal that the caps are not distinct from the cell contents. Thus, the potential beneficial effect of CAD cells on benthic communities may be compromised by design and/or construction challenges rather than from inaccurate predictions of environmental benefits.

Key words: benthic communities, CAD, Boston Harbor, MA

INTRODUCTION

The Boston Harbor Navigation Improvement and Berth Dredging Project (BHNIP) involves dredging shipping channels and berths in the Inner Harbor and its tributaries to increase the efficiency and safety of overall shipping activities in the Port

of Boston. For over three centuries, human and industrial wastes have contaminated Boston Harbor sediments with organic chemicals and metals (Leo *et al.*, 1994). In the 1980s, Boston Harbor was considered one of the most contaminated harbors in the U.S. These contaminants may be damaging or toxic to marine organisms (*e.g.*, benthic infaunal species and bottom feeding organisms) that come in contact with contaminated sediments

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and pore water. In addition, sediments and associated contaminants may be resuspended in the water column or buried by bioturbating organisms (Shull and Yasuda, 2000; Shull, 2001). Affected communities exhibit low species diversity and abundance, and consist primarily of opportunistic species that can tolerate environmentally stressful conditions (USACE and Massport, 1995). Benthic communities in the Inner Harbor and tributaries are characteristic of those found in contaminated environments.

The sediments deposited in Boston Harbor since the last dredging project were deemed unsuitable for open ocean disposal. Confined aquatic disposal (CAD) cells were determined to be the least environmentally damaging disposal option for the project (USACE and Massport, 1995). In this method, dredged sediments are deposited into a pit constructed in the channel bottom, and the contents of the CAD cells are covered with a cap of clean sand. In theory, the contaminated sediments are concentrated into the cells, and pollutants are sequestered by the caps. A potential additional benefit is that the cap may provide a clean substrate for benthic colonization and the change in grain size may attract a different group of organisms. Thus, sand-sapped CAD cells may influence changes in the benthic community.

In July 1997, a Phase I CAD cell was constructed and filled with contaminated dredged sediments (MA DEP, 1998). Preliminary data gathered in September 1997 indicate that the cap was not evenly distributed, covering only approximately 70% of the cell, with the remaining 30% of the cell surface consisting of exposed contaminated dredged material (Fitzgerald and Shull, 1997; Shull and Fitzgerald, 1997). Additional cells were constructed as part of Phase II of the project in 1999.

The purpose of this study was to evaluate differences between pre- and post-project conditions with regards to benthic colonization and sediment contaminant levels in capped cells and uncapped sediments. The capped cells were expected to have different benthic community structures, cleaner sediments, and less organic material than uncapped sediments. Data on sediment characteristics and infaunal communities were collected from the Phase I pilot cell, the Phase II cell "M12", and undisturbed areas of the Inner Confluence and

Mystic River in April 1999. These findings provide baseline data on early cap colonization, and when compared to post-project benthic monitoring studies, contribute to understanding the short- and long-term biological and chemical effects of confined aquatic disposal.

METHODS AND RESULTS

Water quality data, sediment profile images (SPIs), and grab samples were collected from stations at the Inner Confluence cell (IC), cell M12 (M12), and ambient (AMB) locations in the Inner Confluence (AMB-IC) and Mystic River (AMB-MYS). All grab samples and SPI collection methods closely followed the protocols established by the Benthic Monitoring component of the MWRA's Harbor and Outfall Monitoring Project (Kropp and Boyle, 1998). Two sampling trips were conducted on April 12 and April 29, 1999 on Northeastern University's RV Mysis, a fifty-foot research vessel out of Lynn, Massachusetts. Several random coordinate sets were generated within each of the proposed sampling areas (IC, M12, AMB) as target sampling points. During SPI and grab deployment, the time, vessel position, and water depths were recorded. Depth data were later corrected to account for vessel draft, and normalized to Mean Lower Low Water using six-minute water level heights recorded at the National Ocean Service (NOS) Boston Harbor Tide Station (#8443970) on the sampling dates.

WATER QUALITY

Water quality data were collected from twelve stations using a YSI 6820 hand-held instrument. During each deployment, the following parameters were recorded at the surface and bottom of the water column: depth, temperature, salinity, specific conductivity, dissolved oxygen, turbidity, and pH.

Daytime water temperatures ranged from 46.3°F to 54.6°F at the surface, and from 44.0°F to 44.8°F at depth. Salinity fluctuations were minimal among all stations. Surface waters, ranging from 25.48 psu to 26.27 psu, were slightly less saline than waters at depth, with measurements ranging from 26.45 psu to 27.90 psu. Salinity values were low overall, possibly reflecting spring runoff.

Table 1. Sediment types, redox potential depths (RPDs), and particulate organic carbon (POC) composition. Sediment types were estimated from sediment profile images (SPI), and measured from grain size analyses of chemistry grabs (percentages). RPDs (cm) were measured from SPI, chemistry grabs, and invertebrate grabs. For POC analyses, marine sediment (National Research Council of Canada) was used as a standard reference material (SRM), and POC composition measured from two SRM samples were 2.08% and 2.10%. Actual percentage of POC for SRM = 2.19 \pm 0.09%. Asterisk (*) indicates no sample collected from that station.

Station ID	Grain Size Description from SPI and Percentage from Sieve/Gravimetric Analyses				Redox Potential Depth (cm) from SPI and Grab Samples			Particulate Organic Carbon Composition (%)
	SPI	% Sand	% Silt	% Clay	SPI	Chemistry Grab	Invertebrate Grab	
IC-1	Fine sandy silt	11.95	61.01	27.04	3.0	2.5-4.5	2.5	2.91
IC-2	Mud	11.22	62.71	26.07	1.0	4.5	4.5	3.02
IC-3	Mud	*	*	*	3.0	*	*	*
IC-4	Mud	*	*	*	<1.0	*	*	*
M5-1	Sand, shell	*	*	*	2.5	*	*	*
M12-1	Mud	32.28	71.80	4.08	<0.5	0.0	0.0	2.61
M12-2	Mud	1.86	43.88	54.26	<0.5	*	*	*
M12-3	Mud	15.87	48.85	35.28	<0.5	*	*	*
M12-4	Mud	*	*	*	0.0	*	*	*
M12-5	Mud	*	*	*	0.0	*	*	*
AMB-IC-1	Fine sandy silt	19.70	67.53	12.77	1.0	2.5	3.0	2.63
AMB-IC-2	Mud	11.77	61.98	26.25	2.0	4.0	4.3	2.99
AMB-IC-3	*	14.65	66.47	18.88	*	1.5	3.6	2.56
AMB-IC-4	3.0	13.07	57.86	29.06	3.0	4.0	4.3	2.90
AMB-IC-5	*	28.16	69.53	2.32	*	1.5	3.6	2.60
AMB-IC-6	Mud	*	*	*	1.5	*	*	*
AMB-MYS-7	Fine sandy silt	*	*	*	<1.0	0.5-3.0	2.5-3.5	2.66
AMB-MYS-8	Sand	1.86	43.88	54.26	1.0	0.0	0.0	0.16
AMB-MYS-9	Sand	15.87	48.85	35.28	<1.0	0.0	0.0	0.20
AMB-MYS-10	Soft mud	*	*	*	<0.5	*	*	*

Dissolved oxygen levels ranged from 9.8 mg/L to 11.5 mg/L at the surface, and from 8.1 mg/L to 10.3 mg/L at depth. Dissolved oxygen levels were lower at depth for thirteen of the fourteen water quality profiles collected for this study. pH values were fairly consistent among all stations, ranging from 8.0 to 8.2 at the surface, and from 7.8 to 8.1 at the bottom of the water column. Turbidity measurements differed between surface and depth levels. Surface levels for IC stations ranged from 0.04 ntu to 17.7 ntu, and from 12.4 ntu to 650 ntu at depth. Surface levels for M12 stations ranged from 0.9 ntu to 1.7 ntu, and from 1272 ntu to 1762 ntu at depth. Surface levels for ambient stations ranged from 1.3 ntu to 5.2 ntu, and from 698 ntu to 1080 ntu at depth. Higher turbidity levels at depth for the M12 and ambient stations are consistent with the silty surface sediments found at those locations, proximity to major shipping lanes, and M12's recent construction.

SEDIMENT PROFILE IMAGES

Sediment profile images (SPIs) were collected

from eighteen stations. Because the still camera was not functioning on the day of sampling, all deployments were recorded on VHS video. The footage was qualitatively (rather than quantitatively) reviewed for following parameters: prism penetration, apparent redox potential depth (RPD), sediment type, sediment layers, and the presence of tubes, burrows, oxic voids, anoxic voids, and gas voids.

RPD (Table 1) determined from SPIs for M5 and the five M12 stations were all less than 0.5cm. RPDs for the four IC stations ranged from less than 1cm to 3cm. The eight ambient stations also had RPDs ranging from less than 1cm to 3cm. RPDs measured from chemistry and invertebrate grabs are generally consistent with those measured from SPIs. Slight variations in the values may be due to variability in the substrate at the stations, as the grab and SPI apparatus likely did not touch down at exactly the same location. Visual and grain size analysis of sediment type ranged from mud to silt to sand including some shells (M5) and fine-sandy silt (M12 and IC) (Table 1). Invertebrate burrows were visible in two of the ambient station images and two of the Inner Confluence images. Tubes

were visible in four ambient station images and all four IC images. Neither burrows nor tubes were visible in the M12 station images, perhaps due to more recent disturbance. Biogenic mounds, biogenic pits, and/or mysid shrimp were visible at one IC and three ambient stations. Paleomonid shrimp were visible at the M5 station. Mysid shrimp, foraminifers, and occasionally mollusks (bivalves and gastropods) were observed in the samples, but not in the subsamples, and were not included in the invertebrate analyses.

GRAB SAMPLING

A 0.04m² Ted Young-modified Van Veen grab was used to collect samples from eleven stations. At each station two grabs were taken, one each for biological and chemical analyses. Prior to subsampling each grab, the grab penetration and sediment color were recorded. In addition, a modified 60 cc plastic syringe used to take a core of the grab contents from which the apparent redox potential depths (RPD) were measured. Three replicate infaunal subsamples were obtained from each infaunal grab using modified 60cc plastic syringes. After the volume of each subsample was recorded, each subsample and the remainder of the grab contents were individually washed thoroughly through a 300 µm-mesh sieve with seawater and stored in a 10% borate-buffered formalin solution in separate containers. For the chemistry grabs, the top two centimeters of the sediment at grab's surface were removed using a stainless steel scoop and homogenized in a glass bowl. The homogenized sediment was then subsampled for grain size, trace metals, organics, and particulate organic carbon analyses and placed into separate containers.

BENTHIC INFAUNA

Infaunal subsamples were re-sieved through a 300 µm mesh sieve using distilled water and transferred to a 70% ethanol solution for storage. Prior to sorting, subsamples were stained in a saturated Rose Bengal solution. The subsamples were then rinsed with fresh 70% ethanol solution and sorted under a dissecting microscope. Sorted subsamples were returned to a fresh 70% ethanol solution for storage.

Seven species of polychaete worms were found for all stations. These and other organisms found included *Polydora ligni*, *Cirratulus cirratus*, *Streblospiro benedicti*, *Nephtys* species, *Capitella* species, *Polynoidae* juveniles, *Prionospio* species, oligochaetae, nematodae, amphipods, hydroids, crustacean larvae, shrimp, copepods, ostracods, gastropod larvae, and foraminifera. While sample size and grab quantities were small, the organisms found at all stations are characteristic of contaminated habitats (Gallagher and Keay, 1998; Valiela, 1984). No statistical differences in richness ($P=0.921$) or abundance ($P=0.376$) were found between capped and uncapped sediments, nor were any statistical differences found in richness ($P=0.371$) and abundance ($P=0.235$) among samples from the IC cell, M12, and the ambient stations. Because each grab was subsampled to obtain three replicates, richness and abundance data are reported in actual units measured, #spp./0.00589 m² and #individ./0.00196 m² respectively. For the grab size used (0.04 m²), if a full grab was used for each replicate, the richness and abundance data units would be #spp./0.12 m² and #individ./0.04 m², respectively. Richness and abundance values, both actual and extrapolated to units standard to MWRA's Soft-Bottom Benthic Monitoring Program, are compared to those reported for the MWRA Outer Harbor Stations for April sampling (Hilbig *et al.*, 1998) in Table 2.

SEDIMENT GRAIN SIZE

Grain size subsamples were collected from eleven stations, though a processing error occurred with ambient sample AMB-MYS-7. Two additional ambient samples collected in the Mystic River consisted primarily of Boston blue clay. These samples were retained, but were not analyzed because of the clay's high density. The sieve and gravimetric analysis techniques and Krumbein's phi (φ) scale, as described by Folk (1974), were used to determine the sand, silt, and clay fractions of the samples.

All samples contained a majority of silts and clays (fines), with fines fractions consistently larger than sand fractions (Table 1). No gravel was present in any of the samples. Percent sand ranged from 2% to 28% for all stations. Mean percent sand for

Table 2. Richness and abundance for Inner and Outer Harbor stations compared between results of this study and MWRA's Soft-Bottom Benthic Monitoring Program (Hilbig *et al.*, 1998). For purposes of comparison, extrapolated range was calculated by extrapolating data to match the grab volumes typically reported for a 0.04m² grab sampler. (¹This study, ²Hilbig *et al.*, 1996).

	Inner Harbor ¹	Inner Harbor ¹	Outer Harbor ²	Outer Harbor ²
Parameter	-April 1999 -Actual range	-April 1999 -Extrapolated range	-April 1996 -Actual range	-April 1997 -Actual range
Richness	1-7 spp./0.00589m ²	20-143 spp./0.12m ²	21-70 spp./0.12m ²	18-60 spp./0.12m ²
Abundance	0.33-8.33 indiv./0.00196m ²	6.7-169.7 indiv./0.04m ²	160-6830 indiv./0.04m ²	328-5254 indiv./0.04m ²

Table 3. Trace metal concentrations and metal concentrations normalized to fines. BCSS-1 marine sediment (National Research Council of Canada) was used as a standard reference material (SRM). Grain size analysis was not conducted on SRM; trace metal concentrations are not normalized to fines. Concentrations in mg/kg dry weight.

Sample Source	Calculation		Ni	Mn	Cr	Co	Cu	Zn	Cd	Pb
Ambient Inner Confluence (n=5)	Concentration	Mean	32.78	519.42	156.28	12.89	110.57	195.42	8.51	87.62
		St. Dev.	0.62	154.24	46.69	3.91	31.24	54.74	3.75	25.29
	Normalized to fines	Mean	39.29	744.00	248.25	18.27	167.83	302.43	10.17	134.18
		St. Dev.	9.67	165.96	97.69	3.67	53.57	105.26	4.41	45.04
Ambient Mystic River (n=3)	Concentration	Mean	76.44	1367.67	204.75	30.86	109.79	275.38	10.34	90.47
		St. Dev.	13.55	400.48	33.50	8.91	74.91	111.20	14.32	82.98
	Normalized to fines	Mean	92.56	1244.56	283.53	28.09	150.28	327.01	2.23	120.36
		St. Dev.	5.50	460.77	140.26	9.00	118.78	156.46	1.27	105.96
Inner Confluence (n=2)	Concentration	Mean	35.45	591.14	176.38	16.62	125.73	228.33	9.83	94.04
		St. Dev.	0.62	28.57	3.89	1.36	5.29	6.56	1.94	3.73
	Normalized to fines	Mean	40.10	683.41	200.69	18.83	144.02	257.85	11.12	105.63
		St. Dev.	0.93	15.40	3.89	1.60	4.28	9.52	2.26	2.58
M12 (n=1)	Concentration	Mean	53.15	750.24	311.41	17.55	192.40	358.30	15.69	157.90
	Normalized to fines	Mean	57.08	571.43	157.16	13.48	123.64	246.50	17.65	110.12

Table 4. Mean concentrations of selected contaminants in various sediments. Values are listed for sediments from Boston Harbor, pre- and post-BHNIP, this study, Massachusetts Bay Disposal Site (MBDS), Georges Bank shelf, and state (MA Category II) and federal (ER-L and ER-M) limits. Concentrations are in ppm (table after Fredette and Pederson, 1998). (¹MWRA, 1990, ²USACE and Massport, 1995, ³SAIC, 1999b, ⁴USEPA, 1990, ⁵Bothner *et al.*, 1986, ⁶CMR 314.90, ⁷Long and Morgan, 1990).

Pollutant	Boston Harbor ¹	Pre-BHNIP ²	Post-BHNIP ³	This study	MBDS ⁴	Georges Bank ⁵	MA Category II ⁶	ER-L and ER-M ⁷
Cd	2.8	4	3.7	10.3	<4	0.055	5-10	5-9
Cr	133	166	160	205	118	37	100-300	80-145
Cu	105	180	170	110	70	6.5	200-400	85-390
Pb	131	251	220	91	156	17	100-200	35-110
Ni	34	41	43	76	29	12	50-100	30-50
Zn	219	304	380	275	220	30	200-400	120-270

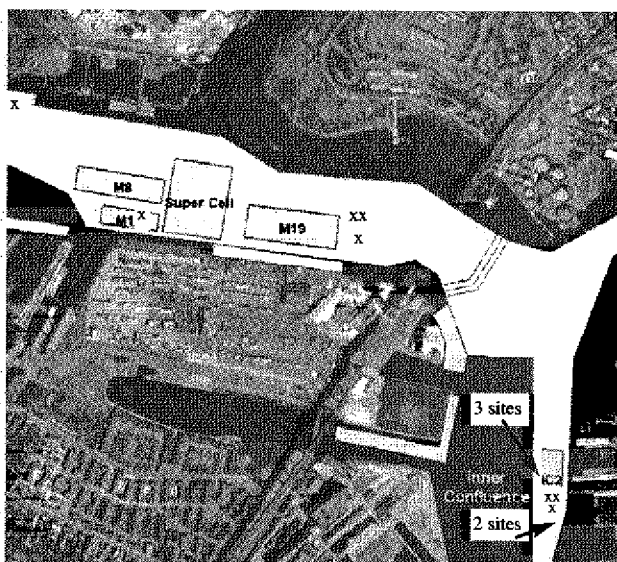


Figure 1. Location for 13 sampling stations. Sediment profile images were collected on April 12, 1999, and invertebrate and chemistry samples were collected on April 29, 1999. Collection locations are marked with the letter "x".

the IC cell, M12, and ambient stations are 12%, 7%, and 15%, respectively. The Amended Water Quality Certification (MADEP, 1998) for the BHNIP defined one criterion for a successful cap as having surface sediments consisting of 90% - 100% sand. None of the sediments sampled in this study approached this range. No statistical differences in sand composition were found between capped and uncapped sediments ($P=0.449$), nor were any statistical differences found among samples from the Inner Confluence cell, M12, and the ambient stations ($P=0.367$). The contents of cells constructed after the completion of this study were allowed longer consolidation periods. Samples from these cells revealed distinct sand caps (S. Wolf, ENSR, personal communication).

TRACE METALS

Subsamples for trace metals were collected from eleven stations. Samples were digested using the microwave digestion technique described by UMB (1995) and analyzed following the techniques described by Shine *et al.* (1995). Marine sediment supplied by the National Research Council was used as Standard Reference Material (SRM). Means and standard deviations for metal concentrations and for concentrations normalized to fines are presented in Table 3. Trace metal concentrations did not vary greatly among stations. No

statistical differences for any metals concentrations were found between capped and uncapped sediments, nor were any statistical differences found among samples from the Inner Confluence cell, M12, and the ambient stations.

Mean concentrations of selected metals in sediments from Boston Harbor, pre- and post- Boston Harbor Navigation Improvement Project (BHNIP), this study, Massachusetts Bay Disposal Site (MBDS), Georges Bank Shelf, and state and federal guidance level are presented in Table 4. The state and federal guidance values are presented as a range; concentrations below the low value are considered clean, and concentrations above the high value are considered problematic (Fredette and Pederson, 1998). Concentrations found by this study are higher than the pre- and post-BHNIP values for Cd, Cr, and Ni, but lower than pre- and post-BHNIP values for Cu, Pb, and Zn. With the exception of Pb, concentrations found by this study are higher than Boston Harbor and MBDS values for all metals. Concentrations at the Georges Bank shelf, typical of an uncontaminated environment, are lower for all metals than the values for this study, Boston Harbor, BHNIP studies, and the MBDS. Concentrations found by this study are slightly above both the state and federal guidance ranges for Cd. For Cr, Ni, and Zn, the concentrations are within the state range, but above the federal range. For Cu and Pb, the concentrations from this study are lower than the state range, but within the federal range.

PARTICULATE ORGANIC CARBON (POC) CONCENTRATIONS

Subsamples for particulate organic carbon (POC) analysis were collected from eleven stations, and were analyzed according to the protocol described by the HUSPH-DEH (1995). Percentages of POC ranged from 0.2% to 3.0% (Table 1). Mean percentage of POC for the IC cell, M12, and undisturbed stations are 3.0%, 2.6%, and 2.1%, respectively. No statistical differences in percentages of POC were found between capped and uncapped sediments ($P=0.194$), nor were any statistical differences found among samples from the Inner Confluence cell, M12, and the ambient stations ($P=0.133$). POC percentages varied little (2.1% - 3.0%), with the exception of

two stations, AMB-MYS-8 (0.2%) and AMB-MYS-9 (0.2%). Clay fractions were highest in the AMB-MYS samples (Table 1), and this may explain the low percentages of POC observed in two of the three AMB-MYS samples. As very little variation in POC percentages is seen among most samples, no correlation between POC and RPD is apparent. RPDs of 1 cm or less were found at the two out-lying stations for POC percentage, as with some stations in other locations.

DISCUSSION AND CONCLUSIONS

This study found few differences between capped and uncapped sediments, or between sediments from the Inner Confluence cell and M12. Benthic communities do not appear to have changed with the creation of CAD cells, nor do the observed communities appear to vary with the age of the cell. Species richness and abundance, generally found to be low in pre-project studies, remain low for the CAD cells. The species found in this study are characteristic of the more polluted areas of Boston Harbor.

To reduce processing time, the invertebrate samples and replicates were smaller in quantity than what is typically collected for a study of this nature. Due to the patchiness of many infaunal communities, the invertebrates collected for this study may not adequately represent the communities sampled. However, the invertebrate, as well as trace metal and grain size data generated by this study are comparable to those reported by several published baseline and monitoring reports (SAIC, 1999b; SAIC, 1997; ENSR, 1997; Fitzgerald and Shull, 1997; Shull and Fitzgerald, 1997; USACE, 1995).

It should be noted that the intended sampling plan for this study was not achieved due to navigational difficulties encountered during sampling, which resulted in unequal and possibly inadequate sample sizes for the three treatments (IC, $n=2$; M12, $n=1$, and AMB, $n=8$). On April 12, 1999, the differential GPS unit was malfunctioning. While GPS coordinates for cell corners were obtained prior to sampling, the depth readings obtained in the vicinity of the cells were often inconsistent, and it was difficult to determine the exact location of a cell. Sediment cores and acoustic data collected from the Inner Confluence cell indicated that

the edges of the cell had likely caved in (SAIC, 1997; Fitzgerald and Shull, 1997), and the cell may have lost its regular rectangular footprint. Finally, the tidal currents in the Inner Confluence and Mystic River may have caused the vessel to drift off mark.

CAD cells are designed to sequester contaminated sediments with a cap of clean sand. However, a distinct, silty surface layer was found at all stations, as determined from sediment profile images, turbidity measurements, and grain size analyses. Sand fractions among sediments sampled from within and adjacent to the pilot cell are low and relatively consistent with each other. Similarly, the Mystic River Ambient samples contain sand fractions similar to the M12 sample. Fines fractions are consistently larger than sand fractions, regardless of the sample origin (in or out of cap). Mixing of the sand layer with underlying fine sediments, and/or misplacement of cap material, are likely to have occurred. Trace metal concentrations from the CAD cell sediments differed little from those found in ambient sediments. If the cells were capped, and benthic organisms were utilizing cleaner sediments, low organic carbon levels and higher redox potential depths would be expected for surface sediments in the cells. However, even if outlying data points are eliminated, no relationship between RPDs and percentage of POC is observed. The high trace metals concentrations in surface sediments appear to correlate to low dissolved oxygen levels measured in this study. Regardless of location, dissolved oxygen levels were lower at depth for nearly all stations.

The results of this and several other studies indicate that for the Inner Confluence cell, cell M12, and other cells constructed in the Mystic River, the goal of a sand cap at the surface of the cells has not fully been achieved (SAIC, 1999; SAIC, 1997; ENSR, 1997; Fitzgerald and Shull, 1997; Shull and Fitzgerald, 1997). Placement of the sand cap is inconsistent, and/or the sand apparently mixes or settles into the silty, liquefied material deposited into the cells. The resulting scenario is one where dredged material remains at least partially exposed at the surface of the cells. In most cases, sediments dredged from the shipping channels and berths are similar to the surrounding ambient conditions with respect to sediment type and contaminant levels (USACE and Massport, 1995).

Effectively, then, exposed dredged material in the cells changes the overall benthic landscape very little. The liquid silty contents of a new cell that have not yet settled may be more likely to be resuspended into the water column by the passage of ship traffic or other turbulence. The surface of completed cells also appears to be slightly below the depth of the surrounding sea bottom. Boston Harbor is an estuarine, and thus depositional, system, subject to processes of sedimentation. The depressed surfaces of the cells may become silted in over time, possibly reducing any beneficial effect of a capped cell should a cap be effectively placed.

The potential environmental benefit of habitat enhancement offered by sand-capped CAD cells is theoretically attainable. However, the physical challenges posed by constructing, filling, and capping the cells to design standards must be overcome in order for a cell to function as intended. In addition, research on local sedimentary processes, the behavior of confined contaminated sediments, and the interaction of these sediments with the water column will contribute to a realistic assessment of the environmental benefits and cost-effectiveness of CAD cells. A well-planned monitoring program is an essential element in developing the CAD design and process. In addition to invertebrate sampling, sediment profiles and measures of sediment contamination, grain size distribution, and water quality assessed at regular intervals will contribute to a better understanding of the impacts of CAD cells on benthic biological communities.

ACKNOWLEDGMENTS

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CHAPTER 2

Confined Disposal Facilities

“Shooting Through the Gas”: Innovative Geophysical Imaging of the Deep Subsurface for Shoreline Disposal Cell Geotechnical Design in a Shallow Marine Environment

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ABSTRACT: A significant technical problem, which has previously hindered the collection of subsurface information in marine environments, has been solved through the modification of a land-based geophysical technique for use in the marine environment. Traditional marine design involves the evaluation of geotechnical design options based upon a limited set of data collected from widely spaced borings and test probes. On land, seismic refraction can be used along with a few drilled borings to generate a relatively clear picture of the bedrock surface. In the marine environment, seismic refraction has not traditionally worked well because of a troublesome characteristic of marine sediments in shallow (harbor and bay) areas. This has forced engineers in the past to drill a significant amount of expensive borings in the water in order to gain the information they need.

The seismic refraction technique does not work well in the marine environment because shallow marine sediments contain a significant amount of organic material which degrades, producing biogenic gas. This “gas” becomes trapped within the sediment. Traditional seismic methods in ocean areas have relied on acoustic signals generated in the water column (air guns, “pingers” and “sparkers”), however these techniques only work in areas where gas is not present in the sediment. An approach that mimics the procedure used on land was developed in order to collect necessary subsurface information in a shallow marine environment for a marine Superfund site clean-up project. By laying out sensors (hydrophones) on the harbor bottom, and burying seismic sources in the harbor bottom (below the gas pockets), the bedrock surface can be imaged, producing results that are comparable with land-based methods.

Key words: imaging technologies, seismic refraction, CDF, New Bedford Harbor, MA

INTRODUCTION

The determination of bedrock profiles and

other subsurface features below the mud-line in the marine environment has been difficult because the high cost of drilling deep boreholes in-water usually limits the number of available monitoring points at any given site. Geophysical methods

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have proven very useful for situations on land, where seismic refraction and reflection has been employed to profile the bedrock and other subsurface features for engineering and environmental purposes (Dobrin 1976, Telford *et al.* 1976). However, marine conditions often interfere with geophysical signatures, particularly seismic, often rendering the results unusable. This paper presents the results of a program designed to overcome the issues associated with the collection of seismic data in the shallow marine environment; a program, which resulted in the collection and interpretation of previously unattainable critical foundation information.

BACKGROUND

The New Bedford Harbor Superfund Site encompasses a large portion of New Bedford Harbor in southeastern Massachusetts; this is depicted in Figure 1 of Borkland *et al.*, "Bottom Imaging...", included in these Proceedings. Sediments within the harbor are contaminated with high levels of polychlorinated biphenyls (PCBs) from historic transformer manufacturing that occurred along the shoreline of the harbor. In 1998, the U.S. Environmental Protection Agency signed a Record of Decision (ROD), which prescribed a remedy for the clean-up of the harbor. The New Bedford Harbor Superfund project is the culmination of several years of consensus-building among federal, state and local environmental agencies, city officials, and an informed and involved public. Numerous prior attempts at designing a remedy had failed to obtain the necessary public support.

The prescribed remedy identified in the ROD calls for the dredging of the contaminated sediments from the floor of the harbor and subsequent isolation of the contaminated material in four permanent shoreline confined disposal facilities (CDFs) constructed for this purpose. The USEPA enlisted the assistance of the U.S. Army Corps of Engineers-New England District (USACE) as manager of the project. Under the New England Total Environmental Restoration Contract (TERC), the USACE assigned Foster Wheeler Environmental Corp. as the lead design/build contractor for the work.

DESIGN ISSUES

The design of the four CDFs was one of the most challenging aspects of the project. Much of the critical foundation information needs for the CDFs were in the shallow marine area adjacent to the shoreline. Lying in between one and thirty feet of water, the area eventually to be covered by the marine-side footprints of the CDFs are underlain by poorly consolidated marine sediments composed of soft organic silts and clays, and silty sands. Bedrock depths range from 30 to 85-feet below mud-line, and test borings conducted in summer 1999 indicated that the bedrock surface is uneven and heavily fractured in places. The largest CDF was to consist of a large cellular bulkhead as the major containment structure, with the ends of the bulkhead tying into shore. The original design concept for this cellular bulkhead involved driving long sheets directly to bedrock. However, when it became clear from the test boring program that the bedrock surface within the project area was highly irregular, the USACE design engineers determined that more extensive information on the bedrock topography and character than could be provided by the test boring program alone would be needed. Detailed knowledge of the extent of irregularity of the bedrock surface had become a critical element in the design process.

THE PROBLEM

If this were a project constructed entirely on land, the collection of the bedrock depth and character information would be fairly straight forward. Several seismic refraction lines shot across the proposed foundation areas, supplemented by a few well-placed borings, would provide the design engineers with the information necessary to conduct options analyses and to then design the selected option. However, in this case, most of the critical information needs are in the marine environment. Traditionally, methods for the collection of bedrock information in shallow marine areas have relied upon seismic techniques involving in-water energy sources for the initiation of seismic energy (either "pingers" or "sparkers"), with sensors also deployed in the water to measure the return signals. The basic principle of operation relies on the energy transfer properties of the water column to

transmit energy into the subsurface (as opposed to land work where the energy and sensors are planted directly into the substrate, resulting in direct energy transfer to the ground). These in-water techniques (known as "sub-bottom profiling") work quite well in areas where there is an absence of an organic bottom layer (*i.e.*, in areas where the harbor bottom is sandy or lacks appreciable organic content). In shallow marine areas, such as is present in most bays, harbors, and tidal flats found on the east coast, an abundance of organic material on the harbor bottom renders these techniques useless for profiling deep structures, such as the bedrock surface. In such areas, the traditional approach has been to drill additional borings. However, this is an expensive prospect given the difficulty and risk involved with marine boring campaigns.

THE GAS CONSTRAINT

The reason that the sub-bottom profiling techniques do not work well in areas of high organic content is because these areas tend to have pockets of biogenic gas trapped in the subsurface. The gas is the result of the decomposition process, which releases methane in the subsurface during the breakdown of the organic material. The gas becomes trapped in the subsurface between and under layers of silty, muddy sediment. The in-water seismic sub-bottom methods all rely on the transfer of energy from the water into the substrate without interference. The energy that is transferred is a pressure-wave (similar to a sound wave), which transmits through solid and liquid medium, but not through gas. Places where biogenic gases are trapped in the subsurface impede the transfer of pressure-waves, and the energy that was intended to be transferred to the subsurface is entirely reflected back into the water column instead, rendering no useful information about the subsurface. Attempts at imaging the subsurface using traditional sub-bottom techniques were made at New Bedford Harbor, with unsatisfactory results (see Figure 1).

OVERCOMING THE PROBLEM

Because the issue of foundation information was so critical to the successful outcome of the New Bedford Harbor project, the USACE asked Foster Wheeler geophysicists if there were a

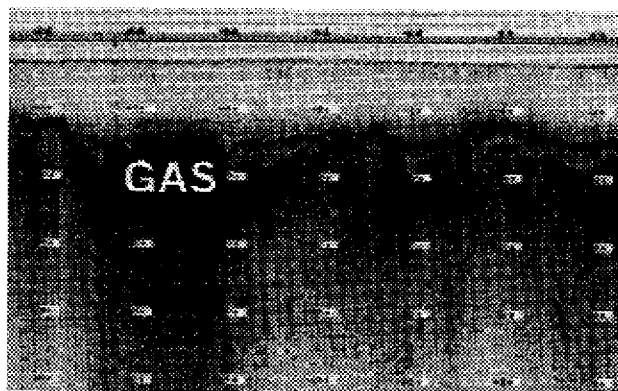


Figure 1. This sub-bottom image shows a gas pocket.

method that could be applied which would image the bedrock surface below areas with energy impeding gas pockets. Recognizing that the key to success on land-side seismic projects is the efficiency at which energy is transmitted into the subsurface, it was decided that a modification of land seismic methods involving direct connection of the energy source and sensors with the substrate stood the best chance of success. A methodology was devised which involved placing high-energy seismic sources (in this case small seismic explosive charges) into the harbor bottom, below the level where much of the biogenic gases accumulate. A device was developed which would allow the charge to be pushed into the substrate and then detonated from a surface vessel. The sensors (in this case a weighted 48-channel seismic bay cable with hydrophones) were likewise laid out on the harbor bottom such that the sensors would lie in the mud on the harbor bottom, providing the best possible connection with the substrate.

RESULTS

The seismic refraction survey was then conducted in the same general fashion as a land seismic survey. Multiple "shots" (middle, end, and off-end) were collected for each hydrophone spread laid out on the harbor bottom. Data was collected with Geometrics 24-channel and Oyo 48-channel seismographs, similar to land refraction surveys. From the very first "shot" set off in the harbor bottom, it became apparent that the technique would generate the kind of results that were required to image the bedrock surface. The seismic refraction records collected in the field (see Figure 2)

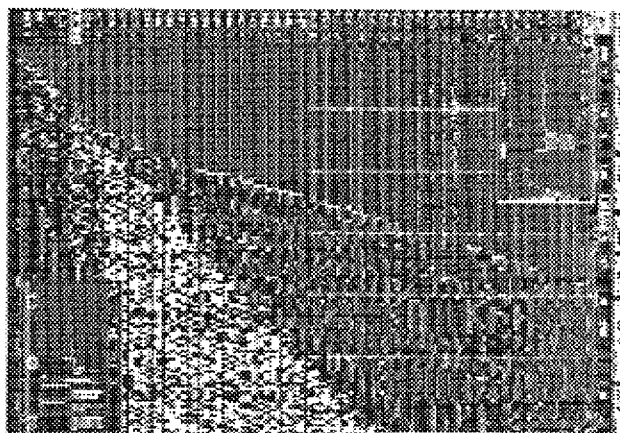


Figure 2. A sample seismic record showing first breaks.

displayed clear “first-breaks” for all channels recorded, and the time-distance ratios apparent on the records indicated that indeed, returns were being clearly received from the bedrock surface. The largest challenge yet to overcome was to obtain accurate position information on each of the shots set off in the harbor bottom, as well as of each of the hydrophones laid out on the harbor bottom.

This information was obtained using a combination of GPS positioning equipment, and side scan sonar underwater imaging equipment. The GPS equipment was used to obtain accurate location

information on the shot points. Side scan sonar was used to image the cable (which had been outfitted with acoustic side scan “targets” prior to deployment) on the harbor bottom, and determine the position of the hydrophones. The data was processed using the same seismic refraction reduction software used for land seismic projects. Initial processing was conducted using the SIPT processing software (Scott 1973), which generates “stick-type” cross-sectional images of the bedrock surface. Because the SIPT models developed for the CDF areas indicated there was the potential for significant fracturing and other irregularities in the bedrock surface to exist, the seismic data was further processed using seismic ray tracing, monte-carlo approach software (Palmer, *et al.* 1980, Singh 1978). The sections processed using the “SeisOpt-2D” software (Optim Software) displayed the variations in seismic wave velocity in the subsurface. These “velocity sections”, when viewed in concert with the SIPT cross-sections (Figure 3), created a clearer picture of the bedrock surface, indicating the presence of several “low-velocity zones” which are interpreted as fracture zones or areas of weathered bedrock with overlying boulders. Sections of the subsurface were produced for each of the seismic lines, generating a three-dimensional structure of the bedrock surface in the areas of the proposed

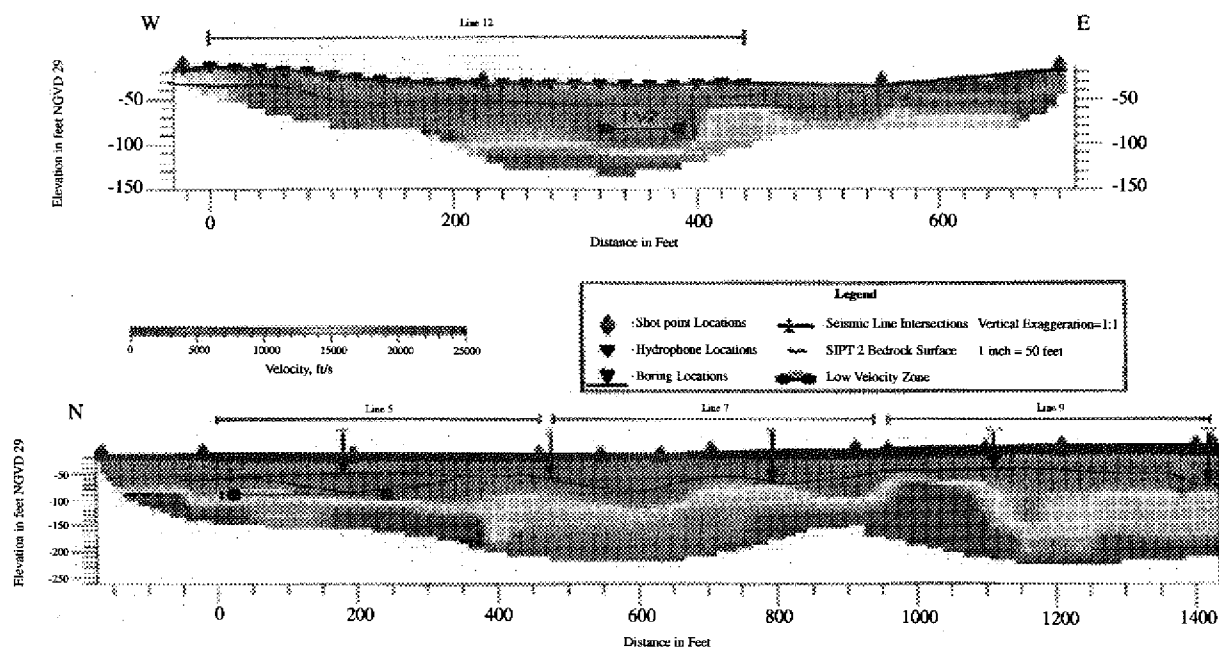


Figure 3. Example seisopt-2D velocity model cross-sections of seismic lines with SIPT model overlay.

CDF walls. Finally, a contour plan of the bedrock surface along the alignment of the CDF walls was produced. Design engineers used this contour map to assess CDF design options. Work in New Bedford Harbor continues, with additional borings and seismic data processing leading to a better understanding of the harbor subsurface.

CONCLUSIONS

The modification of a land-based seismic refraction data collection method was applied to a marine data collection problem with excellent results. Information previously considered unattainable is now available, providing a new method of data collection for engineers seeking details on the subsurface bedrock configuration in marine environments. The benefits include a significant increase in the volume of information available to engineers concerning bedrock character (thus improving interpretations and reducing risk), and a reduction in the cost of obtaining the information that is considered necessary to make conclusions concerning foundations in the marine environment.

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Handling and Treatment of Contaminated Sediments in The Netherlands

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ABSTRACT: From 2000 to 2010, about 200 million cubic meters of heavily polluted sediment are expected to be dredged from the Netherlands. These sediments originate both from environmental (remediation) as well as maintenance cases. Since the 1990s, major progress has been made together with many national and international partners in tackling and improving our knowledge of contaminated sediments. Together, we have conducted extensive research, formulated policy, set guidelines, built large-scale disposal sites, performed remediation and reused dredged material within its area of origin. The Dutch Ministry of Transport, Public Works and Water Management plays a major role concerning the removal and disposal of contaminated sediment.

Recently a large-scale study involving an evaluation (cost and environment) of sediment treatment and disposal options showed once again the necessity of regional disposal sites. The same study also concluded that about 30% of the disposed contaminated sediments could be reused using simple techniques like sedimentation basins. Other recent studies have shown the feasibility of the use of local pits for the long-term storage of contaminated sediments. If one is careful and selects only suitable sites, an overall efficiency of 99% can be achieved.

Key words: regional disposal sites, reuse, CDF, The Netherlands

INTRODUCTION

‘Sludge from the Rhine’: that is what Napoleon Bonaparte called the Netherlands back then. Although intended as an insult, this is an apt description of the Dutch landscape, given the enormous deposits of sediment in the ‘settling basin’ that the Netherlands just happens to be. Figure 1 shows the close relation between land and water in the Netherlands. Although the quality of this sediment is now somewhat better, in the 1960s through the 1980s it was anything but clean. As a heritage from the past, we expect that for the period from 2000 to 2010 alone, about 200 million m³ of heavily polluted sediment will be dredged. These sediments originate both from remedial (environmental) as well as dredging projects. Since the 1990s, major progress has been

made together with many national and international partners in tackling and improving our knowledge of contaminated sediments. Together, we have conducted extensive research, formulated policies, set guidelines, built large-scale disposal sites, performed remediations and reused dredged material within its area of origin. The Dutch Ministry of Transport, Public Works and Water Management plays a major role concerning the removal and disposal of contaminated sediment.

DUTCH POLICY ON CONTAMINATED DREDGED MATERIAL

The international and Dutch policy on contaminated dredged material (CDM) has successfully led to the large-scale reduction of the discharge sources in the rivers. To address the remaining problems of CDM in Holland, an inventory of contaminated sediments was made. The Dutch quality

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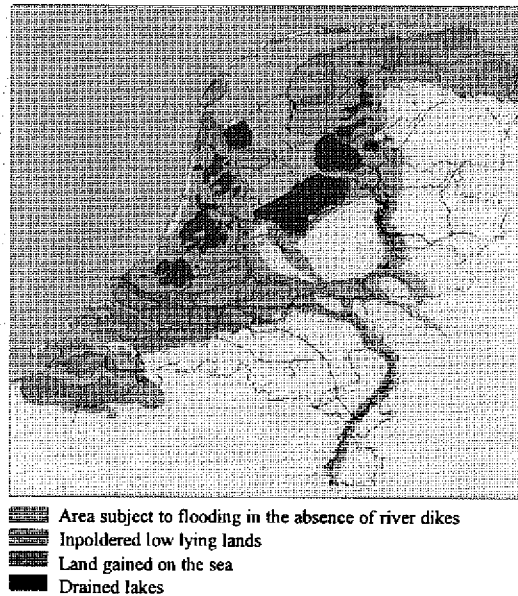


Figure 1. Map showing water management in The Netherlands.

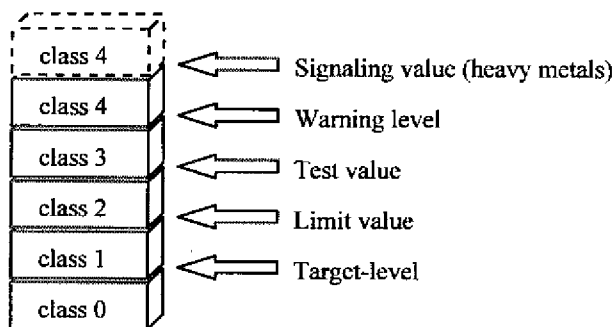


Figure 2. Classes of sediment contamination used for concentration assessment.

assessment uses 5 levels to express the degree of contamination of the sediments. This class-system is based on concentrations of known pollutants in sediment and two soil characteristics (containing organic and clay components). Figure 2 shows the classes used.

When sediment exceeds the warning level it is regarded as a serious case. Since actual risks are strongly related to local conditions, a more detailed hazard assessment is required. This hazard assessment uses both chemical and biological parameters to determine the actual risks. If the hazard assessment shows no (high) actual risks the sediment will be left in place. Only high-risk sediments will be removed.

In case of dredging projects the actual risk will

not be determined since it will be removed from the system anyway. There are 4 destinations possible after removal (spreading, reuse, treatment and disposal). Since spreading is not allowed for heavily contaminated sediments, reuse mostly not possible and treatment too expensive, most heavily contaminated sediments are disposed in large-scale confined disposal facilities (CDFs). Current Dutch policy focuses on the creating of sufficient disposal capacity, intensive research on the assessment system of CDM, and the execution of critical remedial projects. We also try to improve the CDM treatment possibilities.

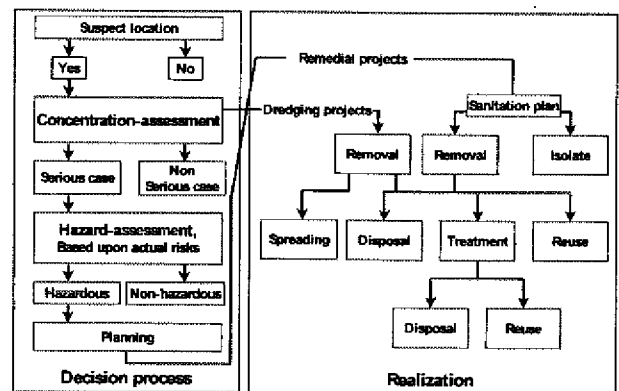


Figure 3. A diagram of the Dutch contaminated dredged material system.

PROBLEMS

There are still some problems that remain to be solved:

- The most important is the large volume of contaminated sediments in the system. Although many discharge sources have been cleaned up, the background concentrations of recent sediment is still far from clean.
- The hazard-assessment is still developing which makes it hard to predict future CDM quantities and qualities.
- Due to opposition mainly caused by Not In My Back Yard (NIMBY), realization of large disposal sites (CDFs) is a big problem.
- The last but not the least of the remaining problems is the lack of operational treatment facilities.

CONSEQUENCES OF NOT DEALING WITH THE SEDIMENT

One could argue to leave the sediments in the system as long as these problems are not solved.

Unfortunately this is not an option for the following reasons:

- Increased threat of flooding in the river systems:
 - this can lead to both a disastrous situation economically and result in loss of human lives,
 - uncontrolled spreading of contaminated sediments.
- Hindrance for commercial and recreational shipping;
- Environmental risks:
 - effects on water for drinking and swimming,
 - dispersion of contaminated sediments,
 - loss of ecological values.

DEVELOPMENTS

There are some important developments that may help solve some of the problems concerning CDM. Recently a large-scale study involving an evaluation (cost and environment) of sediment treatment and disposal options showed once again the necessity of regional disposal sites. The same study also concluded that about 30% of the disposed contaminated sediments could be reused using simple techniques like sedimentation basins. Other recent studies have shown the feasibility of the use of local pits for the long-term storage of contaminated sediments.

CDF: OPEN PITS

In the Netherlands open pits are not yet accepted for use as CDFs. Since there are a number of pits (created from gravel and sand exploration) and there are increasing problems to create atoll-like CDFs (*e.g.*, the Slufter in Rotterdam), the Aquatic Sediment Expert Center (AKWA) examined the use of open pits serving as a CDF. One of the biggest advantages of open pits is the reduction of the NIMBY effect (less visual impact).

The study concluded that the largest sediment losses occur during filling. The largest influence on sediment losses during filling is the current. Although a stronger current will lead to a larger net loss, the risks will decrease with stronger currents.

This opposite effect (higher loss, less risk) is caused by dilution of the pollutants. It is important to be selective with disposal techniques, not all are suitable for filling a pit. If one is careful and selects only suitable sites, an overall efficiency of 99% can be achieved.

CONCLUSIONS

Handling CDM is a major concern in the Netherlands. In the next ten years alone about 200 million m³ of CDM will be removed from our waterways. To determine the toxicity and reuse possibilities of CDM, a class system is used. Although knowledge of risk assessment is available it still needs to be implemented to upgrade the Dutch CDM system. Since there is not enough disposal capacity it will be necessary to use simpler treatment methods to reduce necessary CDF capacity. Since only 30% of CDM is suitable for treatment, up-scaling treatment facilities will not solve the entire capacity problem: additional CDFs must be constructed. Open pits can be a good option as a CDF.

Dredging and Disposal of Contaminated Sediment in The Netherlands

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ABSTRACT: The results of the Dutch research program on the development of remediation techniques for contaminated sediments (POSW) were published in 1997. One of the key conclusions was that complete transformation of contaminated sediments to reusable products was not economically feasible. Based on the results of this program politics decided to focus remediation on dredging and storage of the contaminated sediments in regional Contained Disposal Facilities (CDF). The priorities based on the available budgets are to remove the contaminated sediments from the water system and to store them safely in these CDFs.

Dredging techniques have been developed to dredge selectively the contaminated sediments with minimal negative impact on the surrounding environment. Optimization of the use of the CDF by minimizing the volume to be finally stored is a key item. This will be achieved with a combination of surgical dredging of the contaminated sediments and the use of low-cost treatment techniques, such as soil washing, sand separation, ripening, land farming and CDF-management.

CDFs are in different stages of development: operation, construction, and design in combination with public outreach programs. In order to optimize the total remediation process, it is essential that all stages between pre-investigation, dredging, treatment and final storage fit together. For each project the aspects of importance must be recognized and implemented in the selection of the working method. Based on the experiences with the execution of various remediation projects key items of this process will be addressed.

Key words: remediation, dredging techniques, processing, CDF, The Netherlands

INTRODUCTION

In the mid-1970s, awareness grew that many of the sediments in the Dutch waterways were too polluted for disposal in the North Sea or to be used for unrestricted upland disposal. The Dutch water system forms part of the delta of two of the major rivers in North Western Europe, the Rhine and the Maas. The sediments of these rivers settle in the Dutch estuaries, including the pollutants that were discharged into these rivers along their course from Switzerland, France, Germany and Belgium. The port area of Rotterdam, the main

port to the hinterland covered by these same rivers, needed sufficient depth to receive the deep draft vessels. Maintenance dredging, with a yearly volume of $20\text{--}25 \times 10^6 \text{ m}^3$, is essential for the existence of the Port of Rotterdam. The contaminated sediments were not permitted for disposal at sea anymore in the mid-1980s.

In combination with an active source control program, the Ministry of Public Works and the Port of Rotterdam decided to construct a CDF at the mouth of the access channel to Rotterdam. This CDF was intended to receive the contaminated sediments during a period of fifteen years. It was expected that after these 15 years, source control would be effective and all dredged sediments should be suitable for ocean disposal. The

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"Slufter" CDF was commissioned in 1987 and it has a capacity of 200 million cubic yards. Now, in November 2000, a volume of 100 million cubic yards has been stored in the Slufter. After the successful "Rhine Action Plan" reduced the pollution at the source, the quantity of newly deposited, contaminated sediments was reduced substantially. Annually, 5 million cubic yards of newly deposited sediments is stored in the Slufter. Substantial volumes of sediment from remediation projects up to a distance of 150 miles from Rotterdam have been stored in the Slufter. The Slufter, due to its scale, is still the most economical disposal facility in The Netherlands. The actual disposal cost is US \$5 per cubic yard measured in the barge.



Figure 1. The Slufter Contained Disposal Facility.

REMEDIATION HISTORY

Most of the contaminated sediment in the Netherlands contains a great variety of contaminants resulting from the settlement of large quantities of suspended sediment from the Rhine and Maas rivers in the Dutch Delta. In addition, in The Netherlands, a few dozen hot spots exist due to contamination by the local industry. The first remediation projects were issued in 1988 by means of a contest where the dredging and treatment industry were challenged to propose innovative solutions. These projects suffered from many problems during the full-scale application of the new technologies. Fortunately, a valuable learning process was set in motion.

During this time, the "Development Program on Remediation Processes for Contaminated

Sediments" (POSW) was set up and lasted from 1989 to 1996. This research program focused on site investigation, dredging, treatment and storage of contaminated sediments. Both pilot and full-scale tests were implemented on many techniques. Dredging companies participated actively in this program and special equipment was developed and improved by the execution of full-scale projects.

The conclusions of the POSW program are that sophisticated cleaning techniques for dredged sediments are technically feasible, but are extremely expensive. Minimizing the volume to be stored by selective dredging and applying low-cost techniques such as sand separation (soil washing) and dewatering are the techniques within financial limitations.

DUTCH POLICY

Budgets for remediation of the Dutch water system are limited. The maximum benefit for public health, taking into account this limited budget, is obtained by remediation of the waterways and storing the sediments safely in CDFs. For the clean up of the waterways, adequate dredging techniques focused on high accuracy and minimal turbidity and spillage are critical. Large regional CDFs are the most economic solution because of the size and economy of scale. Additionally, low cost techniques such as sand separation by means of sedimentation or settlement basins and/or hydrocyclones are promoted to optimize the capacity of the CDFs and obtain material for beneficial reuse at a reasonable cost. In the meantime, investigations for cleaning techniques continue at a modest level.

DREDGING OF CONTAMINATED SEDIMENTS

During the execution of the first remediation projects in the late 1980s, grabs in combination with surrounding silt screens were the rule. Evaluation of these projects revealed that this configuration, both from an environmental and an operational point of view, was far from optimal. Accuracy of dredging operations to improve the clean-up result and minimize the volume of clean sediments stored in CDFs became more important. Limits were set on turbidity and spillage. This has

lead to the development of a series of specialized remediation dredging tools. The introduction in 1996 of the Real Time Kinetic (RTK) satellite positioning systems contributed substantially to improve the accurate positioning of the dredging equipment. The accuracy with the new RTK systems is in the order of 5 cm in all three directions.

HYDRAULIC DREDGING

Various hydraulic dredges equipped with a cutting device or knife to make a clear-cut level have been developed by the different dredging companies. The cut material is hydraulically transported directly to a dredge pump. These dredges are appropriate for dredging areas where minimal debris can be found. In those areas, these dredges are most effective and the following features are the key to successful remediation:

- High accuracy for selective dredging;
- Minimal turbidity generation;
- Clean cut with minimal spill;
- Degasification systems installed;
- A flow control system to minimize the volume of water added;
- An active cutting device to cut cohesive and/or sandy sediments;
- Sediments transported via a closed pipeline system, which avoids risk of personal contact;
- The production rate is substantially higher than mechanical dredging devices.

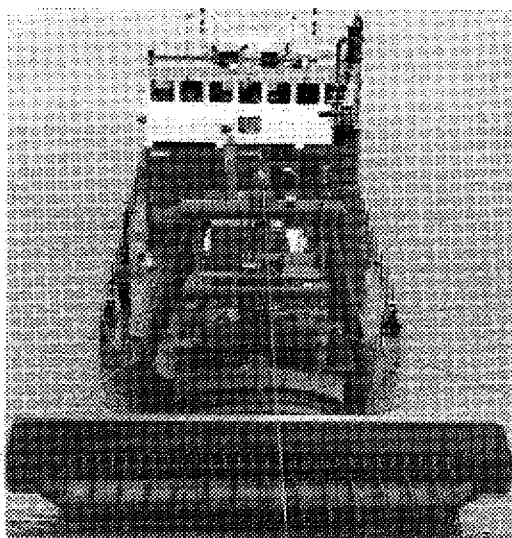


Figure 2. The Auger Dredge

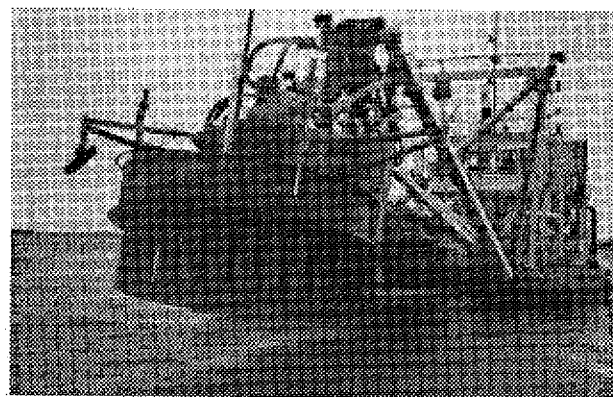


Figure 3. The Environmental Disc Cutter Dredge

PROJECT EXAMPLE

The Ketelmeer, a lake situated at the mouth of the IJssel river, one of the branches of the Rhine, with a length of 10 miles and a width of 3 miles, is a real sedimentation basin for the sediments transported by the IJssel. The upper 30-60 cm of the fine sediment is contaminated. Due to its shallow water depth of less than 3 meters, sediment resuspension occurs at a big scale due to waves and shipping. The sediment volume to be remediated is 15 million cubic yards. To store these sediments, the regional CDF named "Ijsseloog" with a capacity of 30 million cubic yards has just been commissioned. Separation basins next to the CDF have been constructed for low cost sand separation.

Before defining the parameters for the remediation, a dredging contest was established where promising dredging techniques could demonstrate their capabilities. A temporary CDF was constructed for this purpose. Participating dredges were:

- Environmental Disc Cutter Dredge,
- Auger Dredge,
- Sweep Dredge, and
- Environmental Bucket Ladder Dredge.

All dredges passed the test criteria. One of the aspects learned was that more attention had to be paid to an accurate and reproducible position of the interface between contaminated and clean sediments. The accuracy of bathymetric surveys needed more attention to be able to measure within the required accuracy. Calibration of the fathometer was improved by the construction of a fixed underwater benchmark. The full-scale remediation of the Ketelmeer started in September of 2000. The Environmental Disc Cutter Dredge and the Auger Dredge are operating on this project.

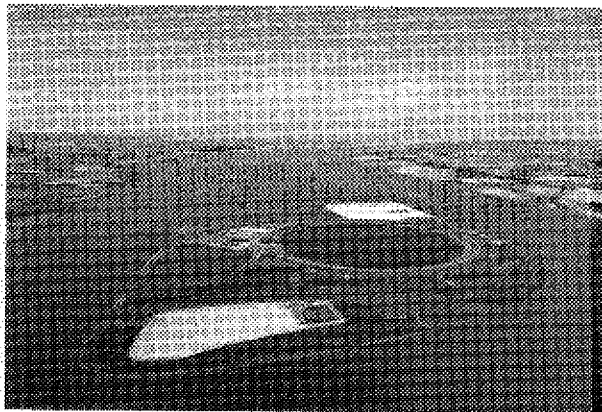


Figure 4. CDF "Ijsscloog" in Ketelmeer Lake

MECHANICAL EXCAVATION

Many areas, where remediation projects have to be executed, are in industrial or urban areas where debris will be encountered. Debris is a major problem for hydraulic dredging processes; therefore in those cases where debris may be expected, mechanical dredging is effectively the only option. For the Elburg remediation project, Boskalis developed the Horizontal Profiling Grab, HPG, in combination with the Crane Monitoring System, CMS. This grab is specifically designed to excavate thin layers of material with a high accuracy, causing minimum spillage and turbidity. The horizontal profiling grab bucket provides a level cut as compared to a conventional clamshell bucket's semi-circular or arched cut. The horizontally closing Profiling Grab is connected via a swivel to a hydraulic excavator. In combination with an active rotator, this system permits accurate positioning and the dredging of a parallel cutting pattern, thus eliminating ridges or windrows after dredging. The large "footprint" of the bucket fosters optimum production in thinner layers of material. Because hydraulic cylinders actively and forcefully close the grab, its vulnerability to debris has proven to be minimal. The grab is fitted with vents, which open when the grab opens and closes when the grab closes. In this way the grab itself is a contained area in which the contaminated sediments are enclosed, and minimal turbidity and spillage are generated during the lifting of the grab through the water column and above the water surface.

The grab is used in combination with the Crane Monitoring System where the actual bottom level, grab position, and levels after dredging are

visualized. Design and actual bottom levels are presented in Digital Terrain Models (DTM). The CMS works by combining signals from the excavator boom, stick, and bucket hinges, signals from the swing of the excavator, the horizontal and vertical position of the RTK antenna, and the list, trim and orientation of the barge. These signals are assimilated in a computer that displays the entire barge system in an animated and graphical format. The digital pre-dredge hydrographic survey and the configuration of the levels to be dredged are visualized. The operator can dredge in pre-set configurations or patterns based on a planned horizontal and vertical grid. The graphical display gives a record of the historical bucket position and grade achieved during a particular anchor set. The HPG, in combination with the CMS, has proven its effectiveness on various remediation projects. During the summer of 2000, Bean Environmental LLC realized a pilot dredge test successfully with this system at The New Bedford Superfund site in Massachusetts.



Figure 5. Horizontal Profiling Grab (HPG)

CDF MANAGEMENT

In the Netherlands, contaminated sediments that do not comply with any criteria for beneficial reuse are stored in CDFs. The large regional CDFs are all atoll-like wet CDFs. Only in special cases are sediments stored in upland dry CDFs. After dredging, the sediments are transported directly either by pipeline, scows, or self-propelled vessels to the CDF. Unloading of the barges is accomplished with a barge unloader. Before the hydraulic transport, some sieving or separation process must remove coarse debris. Sieving devices, such as

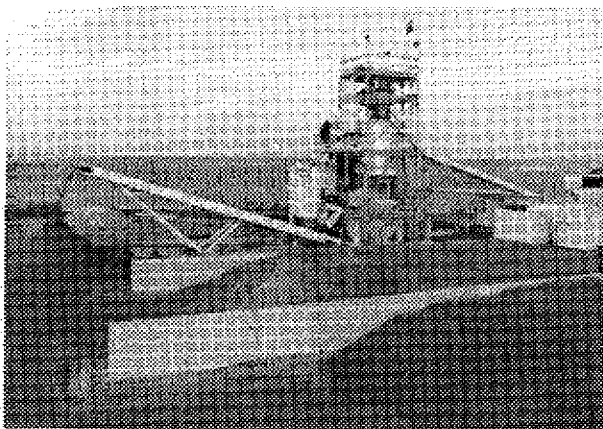


Figure 6. Sand separation at the Slufter CDF.

rotating sieve drums or big rock boxes operated by remote controlled valves, have proven to be more effective than static grizzlies for debris removal.

When unloading or transporting sandy material, the sand is separated either by separation (sedimentation) basins and/or hydro-cyclones. With these low cost techniques, space can be preserved in the CDF and material for beneficial reuse is obtained. The slurry is disposed of in the CDF by means of a diffuser installed close to the bottom for rapid settlement of the sediments and to minimize turbidity.

In case sediments have to be stored in dry disposal facilities (landfills), often dewatering is necessary to facilitate placement of the sediments in the dry landfill. It may also be economically advantageous to dewater these sediments when a tipping fee-per-ton is charged. Dewatering can take place by natural drying or mechanical dewatering. In natural drying, sediments are pumped in basins with a maximum layer thickness in the order of 1 meter. By means of excavating dewatering ditches and creating heaps, with normal earth moving equipment, drying is set in motion. In the North West European climate, annual cycles normally provide material suitable for final disposal in a dry landfill. This method is relatively inexpensive, but also asks for an extensive surface area with sufficient control measures to avoid contamination of the surrounding areas. Mechanical dewatering of dredged sediments has also been applied at full scale on various projects. The advantages are minimum space and time required for processing, and a more controlled process than in the case of natural drying.

CONCLUSIONS

- An integrated approach of all process steps is essential to come to a successful execution of remediation projects.
- Debris is a key element in the design of the remediation method.
- To achieve a successful selective removal of contaminated sediments, maximum attention must be given to accurate site characterization by reproducible pre-investigation and surveying techniques.
- Dredging techniques capable of removing contaminated sediment with high accuracy, minimum turbidity, resuspension, and spillage are operational at full-scale projects.
- As budgets are limited, the maximum benefit for public health is obtained by remediation of the waterways and safe storage of these sediments in large Confined Disposal Facilities.
- To preserve space in the CDFs and maximize the volumes for beneficial re-use, low-cost techniques as soil washing and sand separation located nearby the CDFs are part of the process.

Treatment of PCB Contaminated Dredged Water from the New Bedford Harbor Superfund Project

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ABSTRACT: Operable Unit No. 1 of the New Bedford Harbor Superfund Site will involve the dredging of approximately 750,000 yd³ of PCB contaminated sediments and disposal of the sediments in near shore confined disposal facilities. Wastewaters generated as part of this remedial action will require treatment prior to discharge back into the harbor.

In September 2000, a 165-gpm pilot study was conducted to evaluate the effectiveness of proposed water treatment system to meet the discharge requirements of 0.065 ppb (per Aroclor) for PCBs. The pilot system consisted of: an inclined plate clarifier, chemical addition, sub-micron sand filtration and carbon adsorption. The existing UV/Oxidation system utilized during the Hot Spot sediment removal (Operable Unit No. 2, 1994-95) was also evaluated. The results and conclusions of the pilot study will be presented.

Key words: contaminated sediments, PCBs, water treatment, CDF, New Bedford Harbor, MA

INTRODUCTION

The New Bedford Harbor Superfund Site (the Site), located in Bristol County, Massachusetts, extends from the shallow northern reaches of the Acushnet River estuary south through the commercial harbor of New Bedford and into 17,000 adjacent areas of Buzzards Bay. Industrial and urban development surrounding the harbor has resulted in sediments becoming contaminated with high concentrations of many pollutants, notably polychlorinated biphenyls (PCBs) and heavy metals, with contaminant gradients decreasing from north to south. From the 1940s into the 1970s two electrical capacitor manufacturing facilities, one located near the northern boundary of the site and one located just south of the New Bedford Harbor hurricane barrier, discharged PCB-wastes either directly into the harbor or indirectly via discharges to the City's sewerage system.

The New Bedford Harbor Site has been divided

into three operable units (OU) or phases of site cleanup: The hot spot operable unit (OU #2), the upper and lower harbor operable unit (OU #1), and the Buzzards Bay or outer harbor operable unit. This paper presents the results of a pilot-scale water treatment study conducted in support of the water treatment system design for OU #1.

BACKGROUND

In 1994, a 350 gallon per minute (gpm) water treatment plant (WTP) was constructed at the New Bedford Harbor Superfund Site (Figure 1) to treat wastewaters generated during hydraulic dredging of the Hot Spots sediment (PCBs > 4,000 mg/L) removal activities (OU #2). The WTP consisted of an equalization basin, chemical addition, a settling basin, sand filtration, cartridge filtration, and one (1) 270 kilowatt (kW) Ultraviolet (UV)/Oxidation system. The WTP operated from April 1994 to September 1995 and treated approximately 160 million gallons of water. The discharge limits for PCBs and heavy metals for OU#2 are presented in Table 1.

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Table 1. Monthly average discharge standards

Contaminant	OU #1 Discharge Standard ($\mu\text{g/l}$)	OU #2 Discharge Standard ($\mu\text{g/l}$)
PCBs	0.065 per Aroclor	0.71 $\mu\text{g/l}$ (total)
Cadmium	9.3	6.0
Chromium	50	7.1
Copper	5.6	8.3
Lead	8.5	4.8

For OU #1, approximately 750,000 yd^3 of PCB contaminated sediment (400-500 mg/l average) will be dredged and placed in shoreline confined disposal facilities (CDFs). As with OU#2, the resultant wastewater from dredging will require treatment prior to discharge back into the harbor. However, as shown in Table 1, the PCB discharge limit for OU#1 was reduced by an order of magnitude based on risk assessments and operational data obtained during the OU#2 operations.

In May 1999, the existing WTP was operated to treat accumulated water associated with the stored OU#2 dredge sediments. These tests indicated that the existing UV/Oxidation system would not be able to meet the more stringent discharge limits. However, treatability tests were conducted to simulate the chemical addition and settling anticipated for a full-scale system. Water from these treatability tests was sent to Calgon Carbon

Corporation (Calgon) for UV/Oxidation bench scale testing. The UV/Oxidation bench scale results indicated that given an influent flow rate of 1,200 gpm and a PCB concentration of 2 ppb, the new discharge limit for the 3 to 5 year project could be achieved utilizing the existing 270 kilowatt (kW) system and five (5) additional 360 kW systems. The capital and annual operational costs associated with a 1,200-gpm treatment system were estimated to be \$1.8 million and \$2.1 million, respectively. In addition, Calgon indicated that if the influent concentration were to exceed 2 ppb, additional UV/Oxidation units would be necessary in order to achieve the PCB discharge limit. Therefore, as a result of the high costs associated with UV/Oxidation, Foster Wheeler Environmental Corporation began to investigate carbon adsorption as an alternative tertiary treatment method for the wastewaters from dredging.

Historically, carbon adsorption has been documented as an effective method of removing PCBs from wastewaters. Results of site-specific bench scale granular activated carbon (GAC) tests performed by PACS, Inc. indicated that GAC would be an effective alternative to UV/Oxidation. The capital and annual O&M costs for a 1,200 gpm GAC system were estimated to be \$252,000 and \$131,000, respectively. Therefore, based on bench-scale testing and the potential cost savings

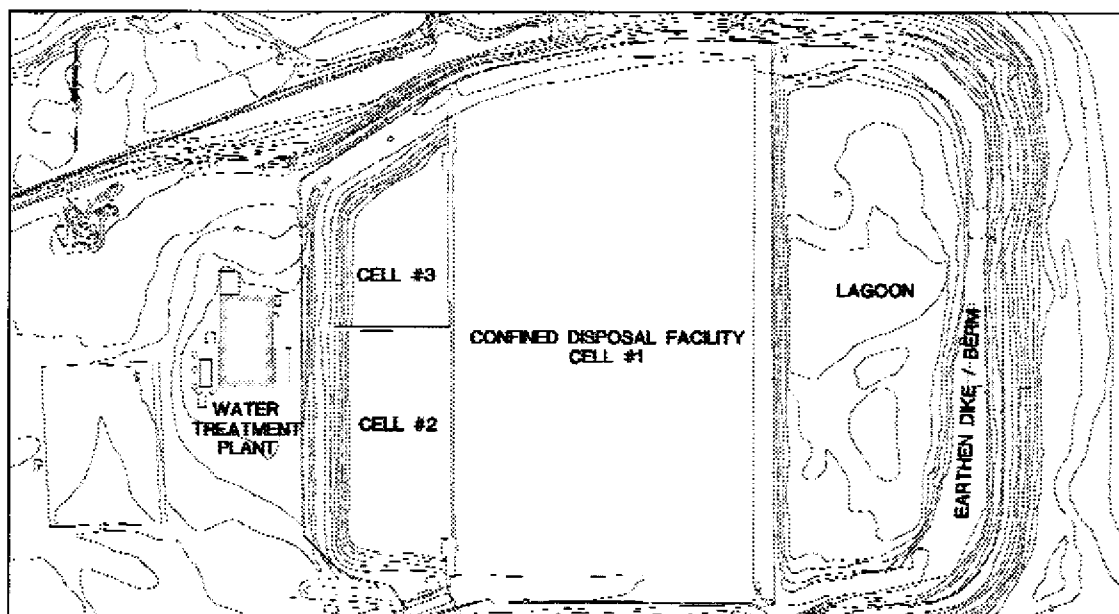


Figure 1. The layout of the existing water treatment plant at the New Bedford Harbor Superfund site.

of GAC, it was determined to conduct a pilot-scale test of the proposed WTP system.

PROCESS DESCRIPTION

The pilot-scale wastewater treatment system was operated from September 11, 2000 through September 29, 2000 and treated approximately 1 million gallons of water generated during the dredging pilot study. The treatment system consisted of chemical addition (alum, polymer), an inclined plate clarifier, ultra-fine (<0.45 μm) sand filtration, and GAC adsorption. Portions of the existing WTP were utilized to conduct the pilot scale tests and the existing UV/Oxidation system was also evaluated using the more aggressive filtration system. The site layout of the pilot scale treatment system is shown in Figure 2 and more detailed descriptions of the individual unit processes are provided in the following sections.

CDF CELL #1

As was done during OU#2, sediments dredged during the dredge pilot study were discharged to

CDF Cell #1. The resulting supernatant was then pumped from the CDF Cell #1 to CDF Cell #2 using a portable pump located at the site. In order to control the concentration of total suspended solids within the supernatant, flexible hose and adjustable piping were used to pump water from varying depths within the cell. The average concentration of PCBs within the dredged sediments was 400 mg/l.

CDF CELL #2

CDF Cell #2 was utilized as an equalization basin prior to the wastewater being pumped to the inclined plate clarifier. Utilizing CDF Cell #2 eliminated any mixing effects that could occur as the dredged slurry was discharged into CDF Cell#1 and provided for a more consistent and representative wastewater stream entering the water treatment system.

INCLINED PLATE CLARIFIER

Wastewater was pumped to the inclined plate clarifier from CDF Cell #2 at approximately 100 gpm.

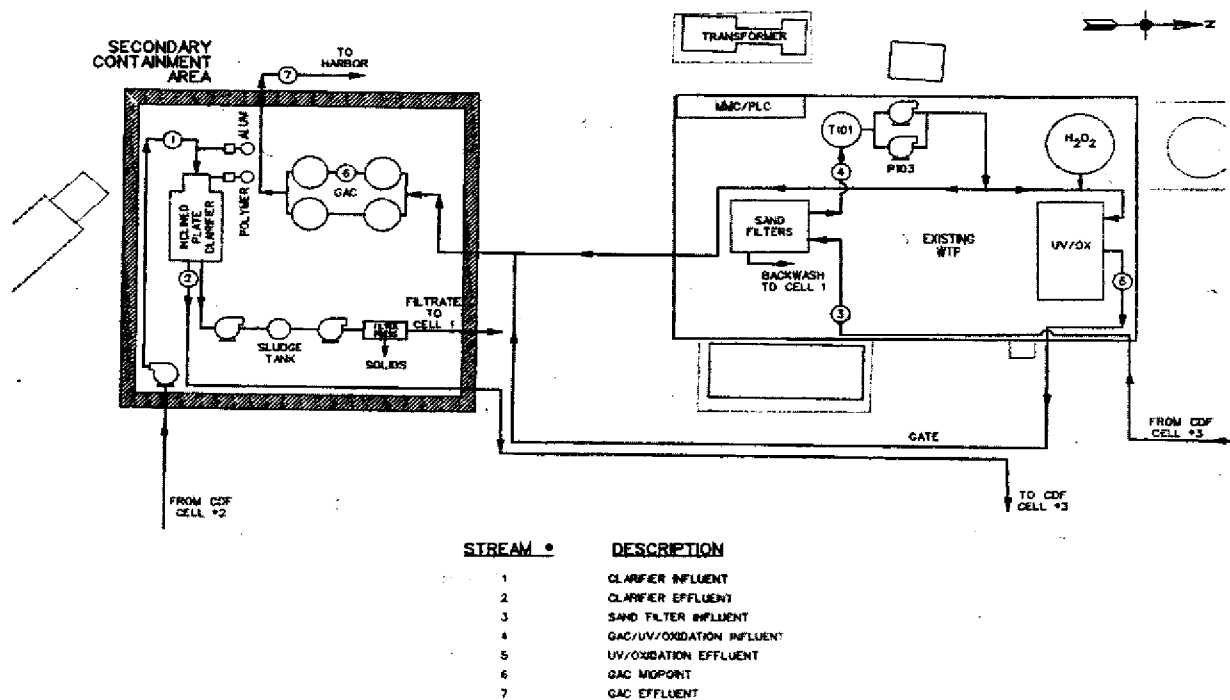


Figure 2. Layout of the pilot-scale treatment system at the New Bedford Harbor Superfund site.

Both alum and polymer were added inline to the influent water before the clarifier flash/slow mix tanks. The pilot scale inclined plate clarifier, which was obtained from another Superfund site, had a capacity of approximately 2,500 gallons and provided a residence time of 25 minutes.

The resultant flocculent settled to the bottom of the clarifier and the effluent gravity flowed into CDF Cell #3. The accumulated sludge was pumped from the bottom of the clarifier into a diaphragm plate and frame filter press for dewatering or back to CDF Cell #1.

CDF CELL #3

CDF Cell #3 was utilized as an equalization basin for the filtration and tertiary treatment systems. Due to the flowrate differential between the clarification and filtration processes, influent water to CDF Cell #3 accumulated at 100 gpm for the first several days of the study. Once approximately 200,000 gallons of wastewater had been collected in CDF Cell #3, the existing sump pumps were used to pump the water at 165 gpm (minimum) through an ultrafine (0.45 μ m) sand filtration unit and subsequently to the GAC polishing units. The CDF Cell #3 pumps were operated for 10 hours per day. The increase in the effluent flow rate (100 gpm vs. 165 gpm) was necessary due to the minimum flowrate requirement (165 gpm) of the existing WTP.

SAND FILTRATION

The sand filtration unit was rated for 0.45 micron nominal filtration and was sized to reduce the total suspended solids (TSS) from 30 mg/L (ppm) to less than 5 ppm. The sand filters were operated at a flow rate of 165 gpm. A recirculation flow rate of 225 gpm was maintained in order to achieve optimal filtration. All backwash water necessary for the periodic cleanout of the sand filters was returned to CDF Cell #1.

GRANULAR ACTIVATED CARBON (GAC)

Four 3000 lbs. GAC vessels (2 sets of 2 carbon vessels in parallel) were placed immediately after the sand filtration to ensure compliance with the

discharge criteria. These GAC vessels were capable of treating a flow rate of 280 gpm, however they were normally operated at a flow rate of 165 gpm. The effluent from the GAC vessels was then discharged to the harbor.

UV/OXIDATION

After completion of pilot testing using the GAC treatment system, the existing UV/Oxidation unit was used to treat the wastewater for an additional five days at a flow rate of 165 gpm (minimum). Effluent from the UV/Oxidation unit flowed through the four GAC vessels for final polishing prior to discharge to the harbor.

PILOT SCALE WTP RESULTS

Water samples were collected before and after each of the unit processes. The water samples were analyzed for turbidity, PCBs, dissolved metals (cadmium, copper, chromium, and lead) and total metals. However, since only PCBs and copper were detected above the discharge limits in the influent stream, only these data are summarized in Table 2.

The data collected indicates that the contaminants present within the wastewaters are strongly associated with the suspended particles and by removing these suspended solids the majority of the contaminants can be removed from the wastewater stream. However, due to the source of the wastewater (seawater) there are colloidal particles present, which flocculation, clarification and filtration alone cannot remove. The concentration of PCBs and copper associated with these colloidal particles is sufficient enough that the wastewater could exceed the discharge limits for OU #1. Therefore, some type of tertiary treatment (GAC or UV/Oxidation) will be required in order to achieve the discharge limits for OU #1.

CONCLUSIONS

Based on the data collected during the pilot scale WTP testing, the following conclusions were made for each of the process operations:

Table 2. Summary of pilot scale WTP results: average PCBs and copper concentrations

Stream # ¹	Turbidity (NTUs)	Total PCBs (µg/l)	Dissolved Copper (µg/l)	Total Copper (µg/l)
1	16.15	7.03	10.48	18.64
2	6.23	6.03	7.37	9.4
3	1.03	1.26	7.87	8.64
4	0.48	0.94	11.92	14.98
5	0.5	< 0.065	15.0	17.4
6	-	< 0.065	<3.0	3.79
7	0.15	< 0.065	< 3.0	< 3.0

¹See Figure 2 for stream identifications

INCLINED PLATE CLARIFIER

An inclined plate clarifier can effectively remove the majority of suspended solids present in the influent stream. The addition of alum and polymer was shown to effectively remove suspended solids present thus reducing the load to the filtration system and increasing the effectiveness of the tertiary system (GAC or UV/Oxidation). The data indicates that the heavy metals are more closely associated with the larger suspended solids that were removed in the clarifier and that the PCBs have more affinity to the smaller pin floc particles that settled out in CDF Cell #3.

SAND FILTRATION

The sand filtration system was promoted as being able to remove <0.45 µm particles. However, the test data indicates that due to the colloidal particles present, the sand filters were only about 60% effective in removing these particles. Therefore, while the sand filters were effective in removing suspended solids, traditional sand filtration systems (< 10 µm) will likely be just as effective. The concentrations of the contaminants within the wastewater stream did not significantly change after passing through the sand filter.

TERTIARY TREATMENT (GAC VERSUS UV/OXIDATION)

Both the GAC and UV/Oxidation systems were shown to be capable of achieving the discharge limit for PCBs during the pilot test.

However, it should be noted that the UV/Oxidation system was only run at half of its flow capacity and as a result the wastewater stream was exposed to twice as much energy. Historical data indicated that the existing system will not be able to meet the lower discharge limits when operated at its design capacity of 350 gpm. In addition, the UV/Oxidation system was not designed for and as a result did not remove the dissolved metals present in the wastewater stream. While not selected for that purpose, GAC was also able to remove the dissolved metals such that the discharge stream met all the discharge requirements.

HEAVY METALS REMOVAL

The existing WTP was not designed to remove dissolved heavy metals present in the wastewater stream and the historical operational data indicated that by removing the majority of the suspended solids the heavy metals discharge limits could still be met. As a result of the OU#2 operational data, it was determined that the OU#1 WTP would not require a dissolved metal removal system.

The pilot scale data indicate that the dissolved copper concentrations were above the discharge limits and, as a result were not removed in the clarification, filtration and UV/Oxidation processes. However, the dissolved metals were removed to below the detection limit in the GAC system. This likely is a result of the GAC being able to further filter the wastewater and remove the colloidal particles that are present in the wastewater stream. In addition, GAC is capable of removing trace amounts of dissolved metals due to the particle charges of the material.

FLEXIBILITY OF GAC VS. UV/OX

Previous studies have indicated that UV/Oxidation can achieve the desired discharge limits if the influent concentration of PCBs does not exceed 2 ppb. Therefore, if the PCB concentration greatly exceeded this level the removal effectiveness would decrease unless the system was designed to handle a higher PCB concentration. The treatment effectiveness of GAC on the other hand is primarily dependent on the absorption capacity of the carbon. If the concentration of PCB varies in the influent, it would only result in

more carbon being exhausted. While this would affect the O&M economics if the concentration remained above the design PCB concentrations, it would not result in an exceedence of the discharge limit.

RECOMMENDATIONS

The anticipated wastewaters resulting from OU#1 sediment dredging can be treated effectively with a WTP that consists of chemical addition, clarification, filtration and carbon adsorption. A water treatment plant which includes GAC would 1) provide for a more flexible treatment system, 2) reduce both PCB and heavy metal concentrations to below the discharge limits, and 3) result in substantially lower capital, and annual O&M costs.

Dewatering Sewage Sludge with Geotextile Tubes

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ABSTRACT: Municipal sewage was placed in geotextile bags to evaluate the dewatering and consolidation capabilities of large geotextile tubes and effluent water quality. A proposed ASTM test method for determining the flow rate of suspended solids from a geotextile containment system for dredged material was used to conduct tests to determine the efficiency of different combinations of geotextile filters. As water passed through the geotextile tube, samples were collected during, immediately after and daily for several weeks to determine the total percent suspended solids (TSS), heavy metals, and bacterial count. The quality of pore water or effluent passing through the geotextile container systems proved to be environmentally acceptable for discharge into the Mississippi River and/or return to the treatment plant. The test results indicated a significant reduction in the sludge volume in the geotextile tube.

Key words: geotextile, dewatering, water quality testing

INTRODUCTION

The United States Environmental Protection Agency and the Mississippi Department of Environmental Quality have restricted the use of many types of waste lagoons such as those operated by municipal drinking water and sewage waste water treatment facilities. The regulatory agencies have issued orders to restrict the use of these facilities, but have failed to provide an economical solution for future waste disposal. Dewatering applications for fine-grained soil from navigation dredged material maintenance projects and sludge lagoons have been limited. Geotextile containers filled with dredged material offer the advantage of ease of placement and constructability, cost effectiveness, minimal impact on the environment, and

confidence in containment. In addition to filling with sandy materials, geotextile containers filled with fine-grained maintenance dredged material provide the opportunity for beneficial use, storage, and subsequent consolidation of this material in dike construction and wetland construction. It has been demonstrated that these geotextile containers retain about 100 percent of the fine-grained maintenance dredged material, therefore retaining the contaminants. The purpose of this demonstration test was to evaluate the dewatering and consolidation capabilities of large geotextile tubes for municipal sewage sludge and the water quality of the effluent passing through the geotextile filter fabric. The scope of this paper is to present the results of the laboratory and field tests, to evaluate the filling methods and techniques, and to evaluate the consolidation and dewatering behavior of a geotextile tube filled with sewage sludge.

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BACKGROUND AND CASE HISTORIES

Since the late 1980's, several thousand geotextile bags, tubes and containers ranging in sizes from 1 to 3,000 cubic meters have been successfully filled with a variety of fill materials in The Netherlands, Germany, France, Japan, Brazil, Australia and the United States and used as submerged stability berms, groins, sill structures for controlling thalweg erosion, scour protection around piers, contraction dikes, dredged material containment and disposal of clean and contaminated materials. For example, geotextile tubes filled hydraulically with fine-grained sand were used extensively on the northern shores of the Netherlands for barrier dikes for subsequent hydraulic fill behind the dikes (Krystian 1994).

The US Army Corps of Engineers (USACE) demonstrated that geotextile tubes 4.6 m (15 ft) wide and 152 m (500 ft) long and 1.5 m (5 ft) high could be filled with fine-grained dredged material for potential use by the Corps of Engineers for dike construction and wetland creation at Gaillard Island Dredged Material Disposal Island, Mobile, AL (USACE 1992). Vegetation growth through containers was very promising; natural propagation occurred after the tubes were filled and the material began to consolidate. The dredged material, at an initial wet bulk density of 1.3 g/ml in the geotubes, consolidated 70% from an initial height of about 1.2 m (48 in) to about 0.4 m (15 in) in about two months.

Geotextile containers, which are dumped either from dump trucks or split hull, bottom dump hopper barges, have been used successfully to construct underwater stability berms, closures for repair of breached dikes, groins, and thalweg scour protection (Duarte *et al.* 1995). These containers have been hydraulically and mechanically filled inside split hull, bottom dump hopper barges, moored in place, and dumped. Design concepts for material tensile strength, seaming requirements, and properties with regard to creep, abrasion, ultraviolet protection, tear, and puncture were documented under the Construction Productivity Advancement Research program at WES.

SEWAGE SLUDGE DEWATERING TESTS

GEOTEC Associates and Nicolon Corporation

have successfully demonstrated that large geotextile bags and geotubes can filter and dewater sewage sludge and retain almost 100 percent of the fine materials. This was achieved in August, 1995, when lime and aluminum sulphate wastes from the Eagle Lake and Culin Water Districts, Vicksburg, Miss., disposal lagoons were placed in two geotextile bags and one geotube (donated by Nicolon Corp.) and closely monitored for filtration and consolidation testing.

The US Environmental Regulatory Agency has required wastewater managers under 40 CFR, Part 503 Regulation and Specific Guidelines, to find other alternatives for dewatering and disposal of sewage sludge, preferably beneficial alternatives, such as combining green waste, fly ash, kiln dust, and/or lime waste and dewatered sewage sludge for land applications. Wastewater managers have been directed to discontinue use of lagoons and submit alternative methods of disposal for approval.

BAG TEST RESULTS

There was limited control over the percent solids for filling the bags on any given day from the sludge digester. However, there did not appear to be much difference in the time of dewatering of the lower or higher percent solids content materials. The higher moisture content sludge material took about 5 days and the lower moisture content materials took about 4 days to achieve about 90 percent consolidation. There also did not appear to be a significant difference in the dewatering capabilities of the nonwoven polyester, Bag 1, versus the polypropylene inner liner, Bag 2. The percent solids, moisture content and wet density approached approximately the same density in about the same amount of time regardless of the initial sludge properties. After a soil filter cake built up on the fabric, the total percent suspended solids (TSS) for both bags stabilized. The initial percent solids in Bags 1 and 2 was 6.6 to 14.9%. The maximum percent solids increase for Bags 1 and 2 was 31% and 33%, for 128 and 132 days, respectively. The TSS passing through the nonwoven polyester geotextile fabrics, Bag 1, performed slightly better than the nonpolypropylene fabrics, Bag 2. TSS for effluent water passing through the polyester fabric was less than 26 mg/l after 11 minutes of drainage and consolidation time. Bacterial

fecal coliform count decreased to less than 100,000 colonies per 100 ml or to a class A material in less than 29 minutes. These tests are not conclusive and it is recommended that a battery of tests be conducted under a more controlled environment.

HEAVY METAL TESTS

Heavy metal content tests were conducted on the effluent water samples passing through the inner liner and outer fabrics for Bag 1 (polyester nonwoven inner liner) and Bag 2 (polypropylene nonwoven inner liner). The results of these tests indicated that arsenic was 1.4 to 1.52 mg/l in the unfiltered sludge and was 0.008 mg/l to nondetect (ND) after passing through the geobag fabrics. Chromium was 1.9 to 4.8 mg/l in the unfiltered sludge and ND after filtration through the geobag. Nickel was 3.2 to 5.8 mg/l before and 0.13 mg/l to ND after passing through the geobag. The detection limits for arsenic, chromium and nickel were 0.005, 0.04 and 0.01 mg/l respectively.

GEOTEXTILE GEOTUBE TESTS

The Nicolon Corporation provided a surplus geotube from a US Corps of Engineers project, Baltimore District, for this research project. The geotube consisted of a 5.3 N/m² (16 oz/sy) nonwoven polypropylene inner liner and a woven polypropylene outer liner for support. The geotube was 4.6 m (15 ft) wide and 9.1 m (30 ft) long.

GEOTUBE FABRICATION

The outer bag liner consisted of Nicolon Geolon GT 500, which is a woven polypropylene fabric that was initially used in geotube construction. Contractors had problems with failure of these fabrics because they neglected to monitor the inlet pressure during filling. Another problem with woven polypropylene fabric is its tendency to fail under high loads due to creep. Because of their low creep properties it is recommended that polyester fabrics be used in all geotube designs unless otherwise specified. The woven polypropylene fabric had an ultimate wide width tensile strength of 70 KN/m (400 pli) in the warp and weft. The tests were conducted using ASTM D 4595 (ASTM 1986) and ASTM D 4884 (ASTM 1990). The

maximum strain was 20 percent in the warp and weft, respectively. The apparent opening size (AOS) was a US Standard sieve number 40-70.

The inner geotube liner consisted of a 5.3 N/m² (16 oz/sy) nonwoven polypropylene geotextile fabric. The polypropylene inner liner has an average thickness of 185 mils. The average grab tensile strength for the polypropylene was 61 KN/m (350 pli). The purpose of the nonwoven fabric was for retention of the fine sludge material. The AOS for the polypropylene nonwoven fabric was a US Standard sieve number 100.

The woven polypropylene fabric seams for the geotube was about 44 KN/m (250 pli) in the warp and weft. All seams were "J" seams. Seams consisted of type 401, double lock stitches that were sewn with a double needle, Union Special Model #80200 sewing machine. The machine is capable of sewing two parallel seams about 0.6 cm (0.25 in) apart. The thread was a 2 ply 1000 denier passing through the needles and 9 ply 1000 denier passing through the looper.

GEOTUBE DATA AND ANALYSIS

A 15 cm (6 in) high wooden frame was constructed to form a box 4.9 m (16 ft) wide and 9.7 m (32 ft) long. The box was lined with a 4-mil thick visqueen liner to contain the effluent water from the geotube. The required pressure, 207 Pa (0.3 psi), to fill the geotube to a height of 1.5 m (5 ft) was determined using a computer program, GEOCOPS. The geotube consolidated 90 percent of its initial height, or area, in the first 26 days after filling. Using geotechnical consolidation theory and an initial measured percent solids of 8 percent, an assumed specific gravity of 2.5, the wet bulk density was determined to be 1.05 g/ml. After 32 days, the wet bulk density was 1.13 g/ml and the percent solids was 19.2%. After 65 days, the wet bulk density was 1.27 g/ml, and the percent solids was 21.0%.

Volume loss and flow rates during the primary self weight consolidation of the sewage sludge in the geotube averaged about 0.06 m³ (15 gallons) daily. After about 26 days loss rates decrease as the geotube accumulates solids during consolidation. The geotube held about 2 cubic yards per linear foot for a 4.6 m (15 ft) wide tube or approximately 45.4 m³ (12,000 gal), whereas a 1.2 m (48 in)

circumference bag 1.5 m (5 ft) long only held 0.18 m³ (48 gallons). The geotube held about 1.5 m³ (404 gal) of sludge per foot. The results from the bag tests may not be used directly to predict geotube performance.

Initially, the geotube was 8.0% solids with a height of 1.5 m (60 in), and the contents settled to 21.4% solids at a height of 0.44 m (17.5 in) after 65 days of consolidation. The geotube was 0.4 m (15 in) high after 120 days. Ninety percent consolidation occurred in the geotube in about 26 days versus 4 to 5 days for the geotextile bags. At 90% consolidation the geotube dropped to a height of 0.5 m (21 in). Based on past experience it was estimated that the geotube would subside to about 0.4 m (15 in) as a result of self-weight consolidation or about 23 percent solids or a reduction of about 75 percent of the initial volume.

CONCLUSIONS AND RECOMMENDATIONS

It was concluded that the geotextile bags and the geotube were capable of retaining the fine-grained sewage sludge and that these materials respond similarly to the soil characteristics of maintenance dredged material. It was shown that geotextiles are capable of filtering the sludge so that the effluent water passing through the fabrics will meet the 30 mg/l discharge requirements in less than 11 minutes of drainage time. It was also concluded that this new and innovative technology is capable of competing economically with other alternative dewatering techniques for sludges. This technique is passive, and does not require extensive or constant labor and maintenance of equipment. This technique is capable of increasing the percent solids to about 22 to 25 percent in relatively short periods of time. This concept of containing sewage sludge has proven to be construction-practical, technically and economically feasible and environmentally acceptable to other disposal alternatives.

It is recommended that additives such as polymers, fly ash, or highly oxidized water etc., be added during or after consolidation in the geotubes to achieve a greater bacterial reduction. One alternative is to do nothing and let the dewatered sludge stabilize naturally in the tube. It is also recommended that small to medium size water and wastewater treatment plants consider the use of this

new and innovative technology for dewatering sludge. Transportable geotubes have been developed for 6.1 to 12.2 m (20 to 40 ft) long dump trucks and/or trailers. The geotubes can be loaded onto the trucks after dewatering. Vacuum consolidation systems are also available for transportable geotubes. Current research is being conducted to substantiate this research effort through an actual full-scale project.

This new and innovative technology has been used successfully to dewater fine grained, contaminated dredged material that contained dioxins, PCBs, PAHs, pesticides and heavy metals for the Port Authority of New York and New Jersey, the Miami River Marine Group and the Port of Oakland, CA (Fowler *et al.* 1995). This is the first successful use of geotextile tubes for dewatering sewage sludge for beneficial uses in the United States. Research using this process for dewatering pork and dairy farming waste, paper mill waste, fly ash, mining waste, chemical sludge lagoons and several other waste streams is being conducted at the University of Illinois.

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Dredging and Dewatering of Hazardous Impoundment Sediment Using the Dry DREdge™ and Geotubes

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ABSTRACT: The purpose of this paper is to describe the application of the Dry DREdge™ technology coupled with Geotubes in the dredging and dewatering of hazardous sediments. The paper describes the project objectives, the Dry DREdge™ and Geotube technologies, and the results of applying this technique. The Dry DREdge™ was jointly developed and tested by DRE and the U.S Army Corps of Engineers, Waterways Experiment Station (WES), Vicksburg, MS, under the Corps of Engineers Construction Productivity Research Program (CPAR).

Key words: geotextile containers, dewatering, impoundment sediment

INTRODUCTION

Ashland Inc. has operated a hazardous waste landfill as part of its refinery operations in Catlettsburg, Kentucky since 1976. The landfill is located in Boyd County, Kentucky, approximately 3 miles south of Catlettsburg, Kentucky. In September 1998, the Kentucky Division of Waste Management was notified that the 20-acre, head of hollow, single cell landfill would be closed by December 1999. Approximately 1.1 million cubic yards of petroleum refinery waste had been land-filled at the site during the past 22 years.

As part of the landfill operation, a wastewater treatment unit was constructed to control surface water discharges. The purpose of the wastewater treatment unit was to collect and treat surface water runoff and leachate that was generated from the landfill during operations. The wastewater

treatment unit consisted of a concrete sedimentation basin and water treatment process, which involved chemical precipitation, ozonation and granular activated carbon processes. The water discharge from the wastewater treatment unit was discharged to a nearby creek and it was monitored under a Kentucky Department of Environmental Safety (KYDES) permit.

The Kentucky Department of Environmental Protection (KYDEP) had requested that all sediments from the concrete basin be removed prior to closing the landfill. In April 1999, it was estimated that approximately 5,000 cubic yards of sediment was contained in the basin. Since the sediment was collected from a hazardous waste landfill, the material was considered to be a listed waste. Analytical testing indicated the principal chemical constituents were semi-volatile organic compounds (*i.e.*, phenanthrene, chrysene, and naphthalene). In April 1999, the KYDEP indicated that it would be feasible to dispose of the sediment from the basin

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in a local landfill during closure and prior to final capping. This option provided a cost-effective alternative to off-site disposal. The only requirements that KYDEP required for disposal was the material needed to pass the paint filter test and no free liquids could remain.

Since the KYDEP approved disposal of the sediment from the basin into the local landfill, it was necessary to evaluate several sediment removal alternatives. Management of contaminated surface water and controlling discharge from the 40-acre watershed during sediment removal was one of the principal factors in evaluating sediment removal technologies. This was significant because runoff could not be diverted around the basin during removal and access to the basin was limited because it was considered a confined space. As a result of the evaluation process, the project team selected The Dry DREdge™ technology combined with in-place, Geotube, dewatering of the wet sediment as the preferred method.

MATERIAL PROPERTIES

Three composite samples were obtained from the basin for geotechnical testing. Particle size distribution and hydrometer tests were conducted to characterize the dredge materials. Plots of these data are shown in Figure 1. Other geotechnical tests conducted included Atterberg Limits (liquid limit and plastic limit), natural water content, specific gravity, and geotechnical description. Results of these tests are shown tabulated in Table 1.

From these test results, the void ratio and the saturated wet unit weight were computed.

The dredged materials were classified as fine-grained dark gray plastic clay (CH to CL) with a trace of sand. Particle size distribution testing showed that composite sample 1 had 90 percent passing a 200 sieve and samples 2 and 3 showed that 99 to 100 percent passing the 200 sieve.

Atterberg limit tests indicated that the dredged material had liquid limits ranging from 45 to 60 and plastic limits ranging from 22 to 25 with the plasticity index varying from 23 to 35. (Atterberg limits are index values determined from soil moisture content.) The specific gravity of the soil material varied from 2.75 to 2.78. The natural water content ranged from 64 to 104 percent with the void ratio ranging from 1.76 to 2.89. The saturated wet unit weights for composite samples 1, 2 and 3 were 1.28, 1.5 and 1.46 g/cc respectively.

The dredged material exhibited water content values greater than the liquid limit, indicating that the material would act as a fluid mud. The dredged material was very soft in consistency and exhibited very low shear strength. When the fine-grained dredged material was clam-shelled from the sedimentation basin and placed into the positive displacement pump hopper, it flowed to the bottom of the hopper.

DREDGE DESCRIPTION

Conventional excavation methods, such as, hydraulic dredging and mechanical dredging with

Table 1. Laboratory testing assignment and data summary of sediment characteristics.

BORING NO	IDENTIFICATION TESTS									REMARKS
	WATER CONTENT w (%)	LIQUID LIMIT LL	PLASTIC LIMIT PLASTIC PL	PLASTIC IND. PI	USCS SYMB. (1)	SIFVF MINUS NO. 200 (%)	HYDROMETER % MINUS 75µm (%)	TOTAL UNIT WEIGHT (pcf)	SPECIFIC GRAVITY G	
Composite 1	64.1	45	22	23	CL	89.1	29	101.0	2.750	
Composite 2	91.8	57	24	33	CH	99.8	45	93.5	2.766	
Composite 3	104.4	60	25	35	CH	99.5	38	90.8	2.776	
	Void Ratio e=w/G	Void Ratio at LL	In Situ Density gr/cc		Volume Reduction to LL	Liquidity Index LI	Activity Ratio A		Ratio w/LL	
Composite 1	1.76	1.237365	1.63		0.81	1.8	0.25		1.42	not sensitive
Composite 2	2.54	1.576506	1.50		0.73	2.1	0.24		1.61	not sensitive
Composite 3	2.90	1.66566	1.46		0.68	2.3	0.25		1.74	not sensitive

Note: Plasticity of fines for United States Conservation Service (USCS) symbol based on visual observation unless Atterberg limits reported.

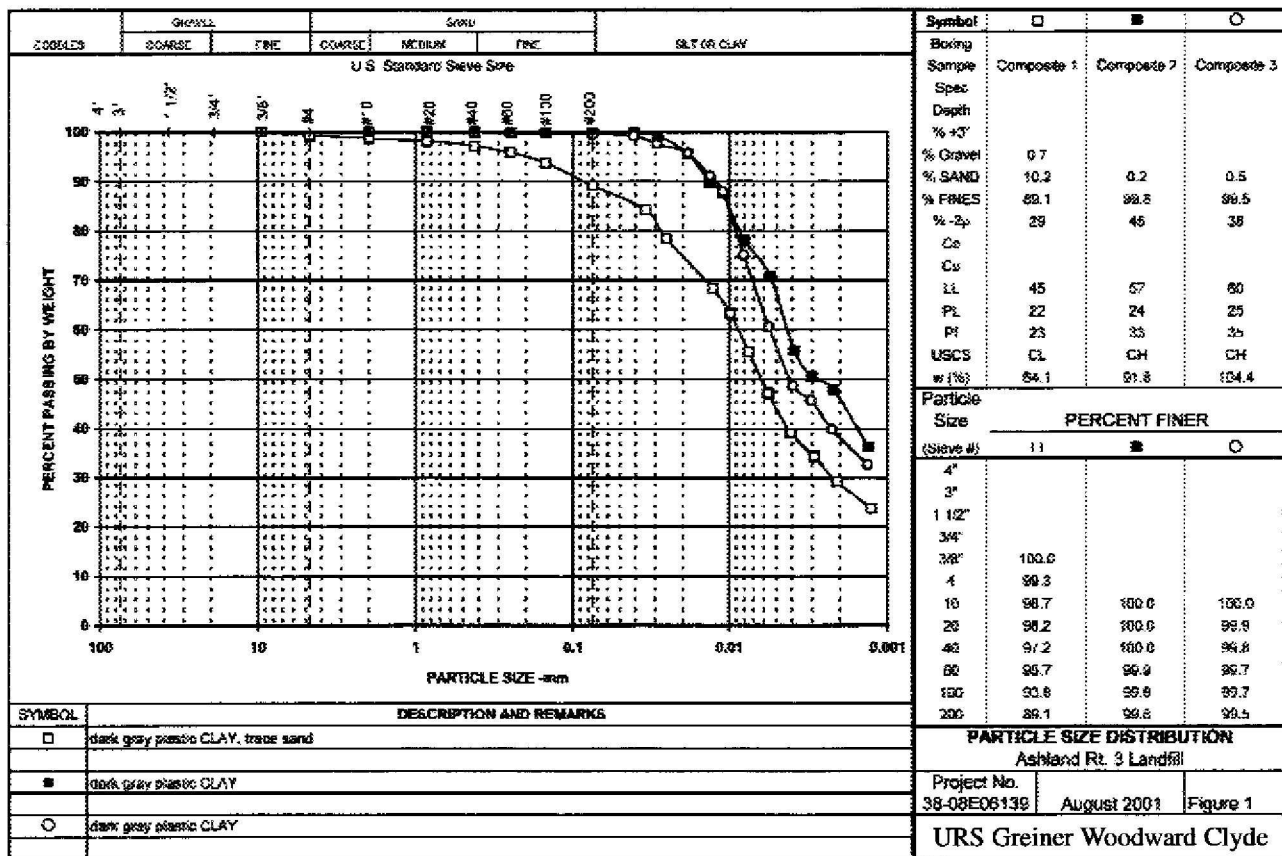


Figure 1. A graph of particle size distribution.

clamshells or draglines typically suffer from several serious limitations. These limitations include significant resuspension of sediments at the point of excavation, imprecise excavation of hot spots, and free water entrainment in sediments requiring expensive dewatering and return water treatment.

The Dry DREdge™ incorporates a specially designed, sealed clamshell mounted on a rigid, extensible boom (see Figure 2). The open clamshell is hydraulically driven into the sediments at low speed, minimizing sediment disturbance and resuspension. The clamshell is then hydraulically closed and sealed, excavating a plug of sediment at its *in situ* moisture content.

The sediment is deposited in the hopper of a positive displacement pump. Depending on the application, the hopper can be equipped for debris screening, size reduction, vapor emission control, sediment homogenization, and blending of additives to modify flow properties or stabilize contaminants. The sediment is pumped in a plastic flow regime through a pipeline to its appropriate disposition. The discharge has the consistency of

toothpaste (see Figure 3). Depending on the *in situ* moisture content and degree of hazard posed by the sediment, the disposition may be direct feed to a dewatering process, thermal treatment or stabilization process, direct feed to on-site land disposal, or direct feed to a transport vehicle.

The most unique advantage of this dredge is its ability to deliver sediments at high solids concentration corresponding to the *in-situ* moisture content. High solids content sediment delivery can offer major economic advantages through the reduction or elimination of dewatering and return water treatment. Solids concentrations up to 70% by weight have been pumped by this dredge (Parchure *et al.* 1997). Other advantages include the following:

- Excavation is accurate and precise. The azimuth, declination, and extension of the clamshell is electronically displayed in the operator's cabin and available for electronic input to a programmable controller. Therefore, the extent of the excavation (length, width, and depth) is controlled easily by the operator. The

programmable controller can be configured to completely excavate the area within range of the dredge by systematically making a grab, depositing the material in the pump hopper, and returning to make another grab immediately adjacent to, or overlapping, the last grab.

- The clamshell-boom configuration allows the dredge to work around rocks and pilings. It is not limited to rectangular excavation patterns as are horizontal auger dredges, or the inverted cone excavation patterns of rotating basket dredges. These excavation capabilities are ideal for hot spot remediation.
- Excavation is achieved with minimal resuspension of sediments. Hydraulic dredge cutter heads agitate the sediments in the vicinity of the pump suction. Conventional clamshells are

allowed to free-fall in order to impact the bottom with enough force to penetrate. Draglines are pulled randomly through the sediments. All these operations disturb the surrounding sediments, resuspending particles and contaminants. Resuspension is a major concern when dredging is conducted in bodies of flowing water such as estuaries. The dredge is intrinsically sound for debris management. Unlike hydraulic dredges, the pump suction is above surface allowing visual inspection of debris by the operator. Debris can be removed or shredded and pumped. The decision-making capability is critical for certain types of debris.

GEOTUBE DESIGN

The design requirements were for a geotube that had a circumference of 90 ft, a height of 5 ft and a length of 160 ft. A maximum wet bulk density of 1.6 g/cc was used in the design analysis. A factor of safety of 5.0 was used in the design, which included factors of safety of 2.0 for seams, 1.5 for creep and 1.5 for biological degradation. A cross-sectional view for the geotube design for this project is shown in Figure 4. This geotube design was determined using a computer program, Geosynthetic Applications Program (GAP), (Palmerton 1998). This program assumes that the geotube is filled with a fluid and does not have any shear strength. The ultimate strength of the geotube is directly dependent on the available wide tensile strength of the seams. Since the seam strength available is 300 pounds per inch width (pli) and the required seam strength is 259.4 pli from the design analysis then the geotextile fabric selected is satisfactory.

GEOTUBE CONSTRUCTION

This project consisted of three 90-ft circumference geotubes, 160 ft long constructed from 15 ft wide panels of a woven polypropylene fabric. Laboratory tests have shown that this woven geotextile fabric has an ultimate breaking strength in the warp of 400 pounds per linear inch width (pli) and in the weft directions of 550 pli at 10 percent elongation for both the warp and weft. These tests have also shown the seam strength to be 300 pli for

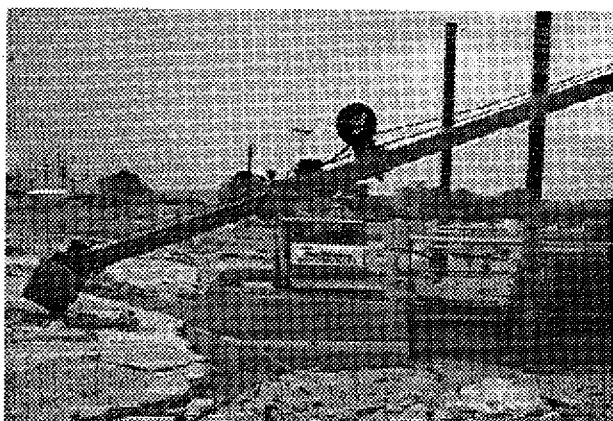


Figure 2. The Dry DREdge™ in operation is shown removing sediments.

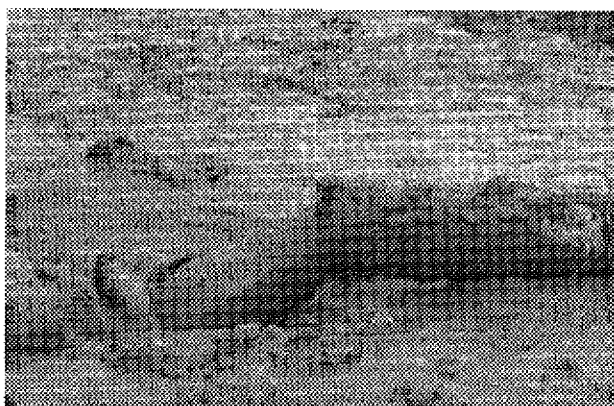


Figure 3. Photograph showing toothpaste consistency of dredged material.

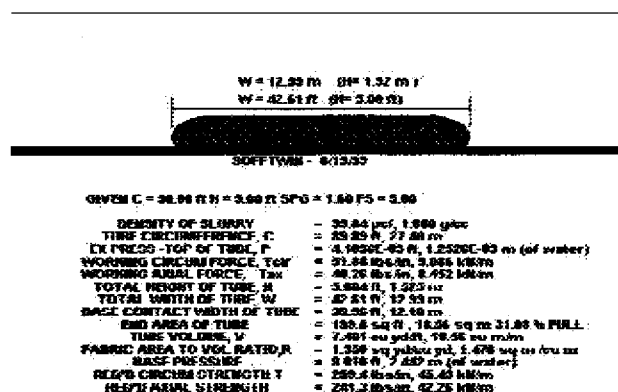


Figure 4. Cross sectional view of geotube and data generated from the geosynthetics application program.

both warp and weft at 10 percent elongation (ASTM 1986). The area opening size (AOS) for the geotube fabric, which is also equivalent to US Standard sieve size number, was about 50 (ASTM 1987).

The geotubes were manufactured by the TC Mirafi Corporation, in Pendergrass, GA and shipped to the project site in a protective covering. Two rows of inlet ports with 1.5-ft diameter, 5-ft long sleeves were provided every 25-ft along the top of the geotube. Nylon anchor straps sewn to the geotube perimeter every 10 ft that were used to secure the geotube prior to and during filling. A 16 oz per square yard nonwoven polypropylene fabric was placed beneath the geotubes to facilitate vertical and lateral drainage during consolidation of the dredged material in the geotube.

A very small amount of fines, less than 5-10 mg/l, were evident in the decant water passing through the geotube during the initial filling but this water became very clear as the geotube was filled to the design height of 5 ft. The decant water looked to have a very light tan to clear color and it was felt to be a insignificant loss of dredged material.

The 15-ft panels were sewn perpendicular to the longitudinal axis of the geotube. All factory seams were sewn with double stitched butterfly seams. All seams consisted of type 401 double lock stitch that was sewn with a double needle Union Special Model #80200 sewing machine. The machine is capable of sewing two parallel rows of stitching about one quarter inch apart. The thread was a 2 ply 1000 denier passing through the needles and 9 ply 1000 denier passing through the looper.

CONCLUSIONS

The project was started in April 1999 and completed in June 1999. Approximately 5,000 cubic yards of material was dredged from the sediment basin and sequentially pumped directly into five geotextile tubes located on the side of a mountain. Filtrate was routed from each dewatering pad to the existing runoff collection system and returned to the basin. Random sampling of collected sediment indicated the majority of the material would pass the paint filter test within 7 days. Limited measurements indicated a free water loss of approximately 20 percent. Observation would indicate the bulk of this water is interstitial. Thus, the use of the Dry DREdge™, geotube technology, and onsite disposal resulted in cost savings of approximately \$1.0 million dollars.

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CHAPTER 3

Beneficial Use

Use of Dredged Materials for Coastal Restoration

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ABSTRACT: Testing and evaluating the contaminant status of dredged material are the first steps to exclude contaminated materials unsuitable for environmental use. Twenty-four case studies from the U.S. Army Corps of Engineers/U.S. Environmental Protection Agency web site on the beneficial uses of dredged materials (<http://www.wes.army.mil/el/dots/budm/index.html>) were summarized. In comparison with the enormous quantities of materials available, the majority of projects were small (less than 100 acres); used sand and silts; used riprap for protection in low to moderate energy environments; and lacked long-term monitoring and research.

Key words: restoration, beneficial use, coastal habitats

INTRODUCTION³

Coastal ecosystems providing vital natural services to society have been severely damaged by development. In addition, the ecosystem functions of large areas of America's remaining natural wetlands have been degraded by subsidence due to groundwater, oil and gas withdrawals, and persistent sea level rise (Delaney *et al.* 2000). Greatest wetland losses in the United States have been in coastal California and the northern Gulf of Mexico (Turner 1997; Zedler *et al.* 1997).

Hundreds of cubic kilometers of sediment are dredged each year for commercial and recreational purposes and discharged into the nation's oceans, estuaries, rivers and lakes, or to land-based disposal facilities. Dredged material containment facilities are nearing capacity or are already full; and opening new containment sites creates numerous social and economic conflicts. Dredged materials are invaluable resources for stabilizing or restoring America's wetlands and beaches; and methods of

wetland restoration using uncontaminated dredged materials are either straightforward, or, are in development. While development may have altered the hydrology of wetland ecosystems and reduced vegetative cover, the hydric soils built through geological time remain. In these cases, wetlands can be restored simply by adding uncontaminated, dredged materials on top of subsiding wetlands. The increased elevation will allow for marsh vegetation to be established. Testing and evaluating the contaminant status of dredged material are the first steps to exclude contaminated materials unsuitable for environmental use.

Twenty-four case studies from the U.S. Army Corps of Engineers/EPA web site (<http://www.wes.army.mil/el/dots/budm/index.html>) on the beneficial uses of dredge materials were summarized (see Table 1). In comparison with the enormous quantities of materials available, the majority of projects were small (less than 100 acres); used sand and silts; used riprap for protection in low to moderate energy environments; and lacked long-term monitoring and research. Costs of projects ranged from \$1.00 to \$11.25 per cubic yard, with a mode of \$1.50.

The Clean Water Action Plan (<http://www.nhq.nrcs.usda.gov/cleanwater/initiative.html>), and the Coastal Wetlands Protection,

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Table 1. Summary of 24 projects from the U.S. Army Corps of Engineers/EPA web site, (<http://www.wes.army.mil/el/dots/budm/index.html>), on the beneficial uses of dredged materials.

Environmental Dredge Projects	Size (acres)	Substrate	Energy Levels	Physical Protection	Costs (yd ³)	Environmental Monitoring/Research Programs
Atchafalaya River, LA	15	Silt	Low	None	2.00	None
Atlantic Intercoastal Waterway	100	Sand, silt	Low	None or riprap	1.00	"Dredged material research program" (DMRP); USFWS/University post-monitoring
Barren Island, MD	100	Sand	Low to moderate	Geotextile tubes a few hundred feet from shoreline	NA	ACE
Columbia River Islands, OR & WA	NA	Sand	Moderate	None	NA	During project only
Core Sound Islands, NC	15	Sand	High	40 ft ² Nylon sandbags	1.50	UNCW; NCSU; ACE post-monitoring
Craney Island, VA	400	Silt	Moderate	Riprap dike	NA	None
Donlin Island, CA	35	Silt, sand	Low	None	1.50	Long-term by UCD & ACE
Folly Island, SC	20	Silt, sand	Low	None	2.28	Local birders; ACE
Gaillard Island, AL	35	Silt, sand	Moderate	Riprap dike	1.25	ACE
Great Lakes Islands, MI & MN	0.5 – 100	Sand, cobble	Moderate	Riprap or none	1.00	Monitored 3x by DMRP; most recently 1985
Gulf Coast Intra-coastal Waterway, FL, AL, TX	0.5 – 100	Sand, silt	Low	Riprap, dikes, or none	1.00	Most of the waterway is not monitored
Hart-Miller Island, MD	1,100	Silt, sand	High	Riprap	NA	MD State Agencies pre-, during, & post-; long-term management plan
Hillsborough Bay, FL	400-500	Sand	High	Limited riprap	11.25	FL State Agencies during project
Mobile, AL	33	Sand, shell, silt	Moderate	None	NA	Short-term within project
Muzzi Marsh, CA	50	Silt, sand	High, variable	None	2.00	CA Coastal Commission; ACE
Pacific Coast Islands, WA, OR, CA	2 – 200	Sand, cobble, volcanic materials	High	None	Less than 1.00	DMRP during project only
Pointe Mouillee, MI	4,600	Sand, silt	High, variable	Reinforced riprap dike & side dikes	9.43	MI State Agencies (DNR); ACE does long-term
Queen Bess Island, CA	8	Silt, sand	Low	None	\$70; 156/acre	LA DNR; ACE during project
Slaughter Creek, MD	4	Silt, sand	Moderate	None	1.50	Pre-, during and post-monitoring by NMSF & ACE
Tennessee-Tombigbee Waterway, AL & MS	14,000	Silt, sand	Low	None	NA	ACE; MSU; MS & AL State Agencies
Texas City, TX	4	Silt, sand	Moderate	Rubble Breakwater	1.25	ACE
Times Beach, NY	25	Silt, sand	Low	CDF dike	NA	Audubon Society; ACE
Warm Springs, CA	100	Silt	High	Dikes; culverts	NA	Pre-project by CA DNR & consultant; Long-term by State Agencies
Weaver Bottoms, MN	5,000	Sand	Moderate	None	NA	ACE; USFWS; MN & WI State Agencies

ACE = U.S. Army Corps of Engineers
 UCD = University of California, Davis
 UNCW = University of North Carolina Wilmington

NCSU = North Carolina State University
 USFWS = U.S. Fish and Wildlife Service
 DNR = Department of Natural Resources
 MSU = Mississippi State University

Planning, and Restoration Act (<http://www.nmfs.gov/habitat/restoration/cwppra/index.htm>) establish the groundwork to increase the area of restored wetlands in the USA. Disposal of uncontaminated dredge materials into the Nation's waters and landfills creates a needless waste of America's ecological, economic, engineering and scientific wealth. Three assessments by National Research Council (NRC) have stated that the restoration of coastal wetland and beach ecosystems is a national priority (NRC 1992, 1994a, b). NRC (1994b) recommended that "Federal science agencies should encourage rapid advancement of the science and engineering of ecosystem restoration and rehabilitation". More collaborative, interdisciplinary studies need to be funded within long-term monitoring programs to evaluate fully the key ecological engineering aspects of using uncontaminated dredge materials for environmental purposes. One noteworthy program is the "Beneficial Use of Dredged Materials Monitoring Program", a collaboration between the U.S. Army Corps of Engineers New Orleans District and the Coastal Research Laboratory, Department of Geology and Geophysics, University of New Orleans (<http://delta.geol.uno.edu/coastal/research/bump/index.html>).

Increased use of dredged materials in coastal areas will make disposal of uncontaminated dredged materials unnecessary. It should be the policy of the United States government and its agencies to use every available uncontaminated cubic yard of dredge materials for beneficial environmental purposes.

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Habitat Creation and the Beneficial Use of Muddy Dredged Material in the United Kingdom

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ABSTRACT: The shape of our coastline is constantly changing due to the impact of natural processes and man-made influences. Coastal areas are under threat from flooding and in many regions sea defences are eroding. Traditionally, heavy engineering has been used to protect coastal areas and high costs have been encountered. New schemes and trials that combat the changes and impacts on our coastlines have started to be undertaken throughout Europe on a small scale, and these have been termed coastal realignment schemes. Coastal realignment schemes are a relatively new approach, and they may involve letting existing land flood, and setting the coastline back, more commonly termed managed retreat, or placing material in front of coastal walls and sea defences and building forward. This paper focuses on the placement of dredged material for building forward of coastal sea walls and sea defences.

HR Wallingford undertakes a number of projects dealing with the beneficial use of dredged material in the marine environment. Of particular interest is the increasing requirement to explore the practical, technical and socially acceptable use of muddy dredged material. HR Wallingford is shortly to complete a Ministry of Agriculture, Fisheries and Food (MAFF)² funded project which involves monitoring schemes where muddy (maintenance dredged material) is placed at estuary sites. This paper reviews the process in the UK for undertaking such projects and practicalities involved. It will summarize the lessons learned from a number of sites where dredged material has been used beneficially for habitat creation. Case studies include salt marsh recharge, mud flat creation and trickle charge feeding of sediments into the estuary system via water column and sub-tidal placements.

Key words: mud, sediments, beneficial use, habitats, sustainability, coastline, United Kingdom

INTRODUCTION

In the United Kingdom there are some 500 separate port terminals handling 550 million tonnes of freight traffic. Through routine maintenance dredging and capital dredging up to 50M

tonnes of dredged material are generated annually and historically much of this material is disposed of to sea. The majority is not contaminated and could be seen as a resource and not a waste.

Coastal and estuarine habitats of interest in the UK include salt marsh and tidal mud flats. Salt marshes occupy some 14% total of the tidal area on British estuaries but are under decline. For example, over one third of existing area of salt

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²Since the paper was written MAFF have reorganised and are now called DEFRA

marsh in parts of the east Anglian coast has already been lost to erosion in as little as 15 years.

Tidal flats vary from soft muds in sheltered inner parts of estuaries to sandy flats in outer, higher energy, areas. They support a vast array of invertebrates (*e.g.*, crustacea, molluscs and worms) and a huge biomass. There are over 265,000 ha of intertidal flats in the UK (Woodrow, 1998).

Coastal and estuarine habitats are of important ecological and conservation value. Over 2M waterfowl depend on UK estuaries, which represent more than 30% of the entire north-west European wintering population (Woodrow, 1998). Many estuarine areas in the UK are now designated sites under the European Habitats Directive. That at least 77 ports operate within or have jurisdiction over 44 sites of international importance clearly demonstrates that a conflict in use of these areas could exist.

Salt marshes and mud flats, however, are also of importance to coastal defence systems. Salt marshes buffer wave energies, offer a natural defence, and reduce required heights and maintenance costs of sea defences (Brampton, 1982; Möller *et al.*, 2000).

On eroding shorelines, the beneficial use of muddy dredged material in habitat creation may have an important role in coastal defences for some UK estuaries and coastlines. Indeed it is recognised that there is an increasing need for more cost-effective sustainable sea defences (MAFF, 2000). Dredged material may be used in the creation or remediation of habitats such as salt marshes and mud flats. This beneficial use would actually meet three aims: to use dredged material beneficially, to maintain or increase biodiversity, and to support coastal defences in a more integrated and hopefully sustainable manner. This paper is interested in the beneficial use of muddy dredged material for habitat creation and coastal processes.

POLICY AND PROCEDURE

The UK is a signatory to a number of international conventions which involve dredged material disposal and biodiversity issues (*e.g.*, London Convention, OSPAR Convention, RAMSAR Convention, Biodiversity Convention). The construction of coastal defence projects or placement of material (sea disposal of dredged material)

below mean high water springs (MHWS) in UK controlled waters, is regulated under Part II of the Food and Environment Protection Agency (FEPA), 1985 (Great Britain, 1985). The Ministry of Agriculture, Fisheries and Food (MAFF) is the designated licensing authority for England and Wales. Other legislation of importance includes the Water Resources Act and the Habitats Regulations, which enact the Habitats Directive.

In considering an application for a license for coastal protection works, the primary objectives stated under FEPA are:

- The protection of the marine environment, the living resources which it supports and human health;
- The prevention of interference with other legitimate uses of the sea; and
- Any other matters the licensing authority deems relevant.

The process is subjective and based on a site-by-site, case by case approach which depends on the risk of impacts occurring as a result of disposal. Presently there are no written guidelines that can be given. It is a pragmatic approach where costs are based on the risks involved. The Centre for Environment, Fisheries and Aquaculture Science (CEFAS) are the scientific advisory body for MAFF. CEFAS and then MAFF under FEPA aim to have enough information so that they can make an informed scientific decision.

The present CEFAS process involves (Matthewson, 2000):

- Information gathering (location and scale of the operation, type of material to be deposited-physical, chemical and biological, methods to be used during construction, timing and duration of the project, consultation with outside organisations and other statutory bodies, *e.g.* CEFAS).
- Assessment and advice by CEFAS and Sea Fisheries Inspectorate (SFI) includes; effects on conservation sites, effects on fish and shellfish resources and fishing activity (CEFAS advise MAFF on fish as a resource and likely impacts while SFI are involved in the commercial side of fishing and catching fish), effects on water quality, effects on coastal processes, effects on other uses and users of the area, provision of an Environmental Statement. A number of schemes have been progressed,

such as at Harwich and Southampton, using sands and gravels for beach nourishment and silts for salt marsh or mudflat feeding. In general, there are perceived difficulties with the co-ordination between a dredging project and the receiving coastal protection scheme, and early discussion with MAFF/CEFAS is encouraged where the beneficial use of dredgings is a possibility.

A FEPA Licence will be issued where the likely environmental effects of the project are considered acceptable and contamination at a level which would be detrimental to the environment is not present. The licence may also require a programme of monitoring work to be undertaken during the construction works to validate the assessment and/or allow action to be taken against an observed impact. Mostly under licence there is a requirement for bathymetry monitoring only with more detailed monitoring for feedback not generally being required.

In recent years a concerted effort to apply beneficial uses to natural resources and environmental projects has been made. Increasing awareness of this fact has prompted MAFF to inaugurate a policy whereby any application for a licence to dispose of dredged material will be required to show that possible beneficial uses have first been properly considered. Some dredged material has potential uses for coastal defence and this is strongly encouraged, not least through the application of lower disposal licence fees.

Whilst there are some ideas on beneficial uses of dredged material outlined in MAFF Coastal Defence and the Environment document (MAFF, 1995) and also published in grey literature, there are no checklists or established guidelines for monitoring and examining them. Nevertheless some beneficial use projects are under active consideration, whilst others are already in progress and some have already been completed (Murray, 1994). Typically beneficial uses have involved coarse material such as beach nourishment schemes. Of increasing interest is the use of more muddy material from maintenance dredging which has been generally considered of less use than gravel and rock from capital dredging.

TYPES OF DREDGER

The main methods of dredging and disposal for

Table 1. Types of dredger and means of disposal/placement.

Dredger type	Means of disposal
Grab	Dredged material may be placed into a barge for bottom dumping or could be placed directly onto an adjacent site.
Grab Hopper	Dredged material may be disposed by bottom dumping or could be grabbed out of the hopper at a placement site.
Static suction	Disposal is via a pipeline. The dredged material contains a high proportion of water. Dredgings could be pumped into a barge.
Trailer suction hopper	Disposal is usually bottom dumping but some vessels can sidecast or have the ability to discharge by pump.
Agitation	Agitation dredging (of all kinds) introduces material into the water column at the dredging site.

muddy material are given in Table 1. Generally, the first four methods involve moving the bed sediments from one site to another while agitation dredging involves making the bed sediments more available for transport and redistribution and transportation within the system at the site of dredging. Grab dredgers will produce natural sediments with a higher density which are less amenable to resuspension and transport while station suction and trailer suction dredgers, by adding larger amounts of water to the sediments, give a slurry which may be readily transported away from the site of placement.

METHODS FOR MUDDY DREDGED MATERIAL

The beneficial use options for muddy material include; Direct placement onto the inter-tidal, confined placement onto the intertidal, direct sub-tidal placement, confined sub-tidal placement, placement behind seawalls to build up land levels prior to managed retreat, inter-tidal trickle charge, sub-tidal trickle charge, water column trickle charge and agitation dredging.

DIRECT PLACEMENT

Direct placement, either on the inter-tidal or sub-tidal, is the placement of material from a dredging operation onto the existing sea bed with-

out construction of retaining structures. The aim of direct placement is to modify the morphology in some environmentally beneficial way, for example, extending the area of an inter-tidal habitat. The major disadvantage of direct placement is that the existing habitat is invariably smothered, because of the depth of the placement and, as the placement is unconfined, the risk of substantial losses of material and associated increases in turbidity is high except in the lowest energy environments. Direct placement in higher energy environments is likely to represent a trickle charge source (see below).

Direct placement could be via a pipeline discharge or through bottom dumping from a hopper. Placement via a pipeline is likely to result in a much weaker material, which is more readily resuspended. Direct placement onto the inter-tidal has been undertaken in the Blackwater as part of the maintenance of salt marshes in the vicinity of Maldon (a few hundred m³ at a time).

CONFINED PLACEMENT

Confined placement is similar to direct placement in terms of scheme objectives. However, the risks of losses of material from the scheme are reduced, and the ability to engineer the scheme is enhanced because of the retaining structures that are incorporated into the scheme. Retaining structures may be either 'soft' structures that are likely to be mobile in the longer term (for example gravel/sand berms), or 'permanent' structures that are in principle immobile (for example a piled structure). The main disadvantages of confined placements are the habitat loss associated with smothering and the potential impact of introducing the retaining structures into the system. The view is held by some that only material of a similar size distribution to that existing at a site should be introduced.

Confined placement is likely to be via a pipeline, although in some instances material might be placed directly into the confined structure by grab or backhoe. A key aspect of the design of a confined placement is the design of the retaining structures such that the normal rise and fall of the tide do not threaten the integrity of the structures before and during placement. A further issue is the fact that the placed material will form a weak slope during placement, but will tend to flatten after placement is completed and de-watering commences.

Confined intertidal placements using maintenance-dredged material have been undertaken in the Orwell estuary (approximately 20,000 m³ of silt and 17,000 m³ of gravel) and on Horsea Island in the Walton Backwaters (approximately 20,000 m³ of silt retained by previously placed gravel). A confined inter-tidal placement using sheet steel piling and capital dredged material has been constructed in Poole Harbour as part of the development of Parkstone Yacht Club (10,000 m³).

PLACEMENT BEHIND SEAWALLS TO RAISE LAND LEVELS PRIOR TO MANAGED RETREAT

This is basically a derivative of confined placement, but applied to the situation where an area of land behind existing seawalls has been identified as appropriate for managed retreat. The simplest placement technique is to pump material behind the seawall. An obvious issue is then whether static dredging plant can be used (requiring the managed retreat site to be close to the dredge site), or whether a trailer suction hopper dredger with a suitable pump-out capability can be used. This requires relatively deep water to be available close to the proposed site. Issues associated with run-off of water from the placement site are of prime importance for this type of approach.

To date no managed retreat sites in the UK have been pre-treated in this manner before breaching. The small Trimley retreat site on the Orwell is likely to be treated in this way. The logistics are similar to many of the silt lagoons created adjacent to small marinas around the UK.

TRICKLE CHARGE

Trickle charge is a concept of recycling dredged material back into the natural system using the energy of the natural system to redistribute the dredged material. The key difference between a placement and trickle charge is that, at the site where the material is released, there is no deliberate intention to make a habitat change. In its simplest form, trickle charge can be seen as the direct alternative to removing material from a natural system by disposing of it offshore.

Intertidal trickle charge is the approach where material is placed on the inter-tidal to disperse. Subtidal trickle charge is the situation where material is

placed sub-tidally to disperse. Subtidal trickle charge is often preferred, as it does not impact on valuable intertidal habitats, and there are more options for placement (via pipeline and bottom dumping). An alternative to intertidal or sub-tidal trickle charge is trickle charge via the water column. In this approach the objective is to discharge material into the water column at such a rate/dilution that the moving water column is able to carry the recharged material away from the site of introduction without significant impacts on the sea bed. Obviously the ability of the water column to carry significant quantities of material in suspension without impacting on the sea bed depends on the energy within the water column (tidal currents and turbulence).

Subtidal trickle charge is ongoing in the Stour Estuary (approximately 100,000 m³) and within Harwich Harbour (400,000 m³). Water column recharge described in the Environmental Statement commenced in the Stour Estuary in the winter of 1999 (HR Wallingford, 1996). Intertidal trickle charge has been undertaken in the Medway Estuary (a few thousand m³).

AGITATION DREDGING

Agitation dredging comes in a variety of forms. The basic aim of agitation dredging is that material is mobilised from the dredge site by some mechanical action (for example bed levelling) or by some hydraulic action (for example water injection or direct discharge from a cutter suction or hopper overflow into the water column). Following mobilization, the natural tidal regime redistributes the agitated material away from the dredge site. Typically agitation dredging is economical on a small scale, requiring relatively unsophisticated plant. Agitation dredging is not normally licensed, but it is under review by MAFF. Agitation dredging is an obvious source for trickle charge, but the type of source and the associated impacts vary with the type of agitation operation. Note that the trickle charge source will be at the dredge site, which is different to the more flexible approach of the trickle charge schemes described above.

Agitation dredging is undertaken on a variety of scales around the UK. For example at the Port of Bristol, all dredging (in the region of 1 Mm³/year)

is by agitation, and at one stage the Port of Felixstowe was largely maintained by water injection dredging techniques (approximately 1 Mm³/year).

LINKING SEDIMENT PROCESSES TO BENEFICIAL USE

Knowledge of the sediment regime of the system within which dredging must take place is presently the key to identifying an acceptable solution to managing the disposal of dredged material. In a highly turbid system large scale agitation dredging may be acceptable and economic. In a low energy system with naturally low suspended sediment concentrations this would probably be unacceptable. Trickle charge links disposal of dredged material to the natural sediment processes. By selecting a site for placement the impacts of the trickle charge can be controlled. By selecting the rates (and possibly timing) of placement, the impacts can be further controlled.

SUITABILITY OF THE MATERIAL

The type of material dredged or the quality (physical, engineering, chemical, physico-chemical and biological impacts) of the sediment to be placed must be determined and related to its suitability for beneficial uses. Most of the dredged material in UK is muddy. The physical properties of the bed sediments are changed as a result of dredging and their subsequent transport away from the placement site will be determined by a number of factors including the surrounding hydrodynamic conditions and the dredged material properties (*e.g.*, density) after placement.

Other factors will also determine the suitability of the material and feasibility of a scheme. These include; the location of the dredging and placement site, scheme design, practicality, timing of the dredging, dredging method, placement method, environmental concerns, legislation and regulatory commitments, previous applications and measures of success, aims and objectives of the scheme, communication between involved parties, information gathering, monitoring, acceptability and public perception and finally, costs. Costs will include the cost of transport, project design, maintenance, land acquisition, equipment mobilization, construction

of protective breakwaters and monitoring.

The measures of success and goals warrant a further mention as how to measure success may need to be clarified and agreed upon at the planning stage and an appropriate monitoring plan set up. For example, environmental goals in a beneficial use scheme may be defined as achieving the goals and objectives based on agreed-upon replacement values of the lost or degraded mud flat resource.

MONITORING

Engineering and environmental monitoring is necessary to collect baseline data prior to, during and following dredging and project construction. Monitoring is important so that the success of a scheme can be evaluated and confidence gained in its further application, in particular because of the relative infancy of the approach in the UK. This will be needed to justify future projects that may need to occur on a larger scale. Case studies can play an important role in developing monitoring methodology as well as gaining knowledge of success.

Monitoring is, therefore, necessary to collect baseline information, collect data for interpretation, document activities and chronology of the project, document success or failure and the need for mid-course correction, justify similar projects in the future, generally improve experience and understanding of the engineering, scientific, economic and environmental factors involved and importantly, improve understanding of sediment processes and to gain confidence in the process and beneficial use of fine dredged material.

CASE STUDIES

MUD FLAT CREATION

Confined placement: Marina in Poole Harbour, South Coast of England
 Placement date: Winter 1994/1995
 Dug out at low tide with excavator and transported by lorry along the breakwater and then placed
 Dredged Material: Firm clay and silt
 Size: 10,000 m³ (area 325 m by 20 m).

A substantial breakwater was constructed with large rocks and rubble to protect the yacht berths and the mud flat was constructed adjacent to this using sheet piling to contain the mud. Construction difficulties with the sheet piling, time restrictions for operation and initially mud was deposited to the wrong level (MHWS). This was reduced in level so that the mud was intertidal.

Monitoring: bed levels, sediment density, macro-invertebrates, birds

MUD FLAT CREATION

Confined placement: Eroding coastline at Shotley, Stour Estuary, Suffolk, England.

Placement date: December 1997

Placed by pipeline from trailer suction hopper dredger

Dredged Material: Silt

Size: 13,000 m³ gravel, 22,000 m³ (area-430 m by 70 m).

Maintenance dredged silt was used for mud flat and confined in a gravel bund constructed from capital dredge material.

Monitoring: bed levels, sediment density, grain size, shear strength, carbon (loss on ignition), macro-invertebrates, birds, wave measurements, suspended solids in flood waters. (HR Wallingford, in press).

SALT MARSH REMEDIATION

Confined placement. Eroding salt marsh at Horsey Island, Hamford Backwaters, England.

Placement dates: February 1998

Placed by pipeline from trailer suction hopper dredger

Dredged Material: Silt

Size: 20,000 m³ (area 27,000 m²)

Wooden brushwood fence was used to contain the inter-tidally placed material. Vegetation was via natural plant colonisation.

Monitoring: shear strength, bed levels, density, vegetation. (HR Wallingford, in press).

TRICKLE CHARGE (SUBTIDAL)

Containment of sediment within sub-tidal depressions at the Horse, Stour Estuary, England.

Placement dates: May 1996

Placed by pipeline from trailer suction hopper dredger

Dredged Material: Silt

Size: 7,800 m³ (area 110 m by 45 m)

Subtidal placement of unconfined dredged material pumped from a trailer suction dredger through a pipeline, which was placed on the bed.

Monitoring: grain size, bulk density, bed density, bed level, suspended solids in water column, currents, modelling of bed shear stresses. (HR Wallingford, in press).

FUTURE WORK IN THE UK

At present, the volumes of muddy maintenance dredged material used beneficially in the UK are very small, and caution should be expressed over any scheme which proposes to dramatically extend the volumes of material used from that outlined in the trials above. For many typical UK dredging operations, the volumes used in the trials described above represent a significant proportion of the annual dredging requirements. In such cases the concept of utilizing a large proportion of the material arising annually from an estuarine system in a beneficial manner cannot be discounted on the basis of any precedent. The trials have led to the feasibility of schemes being realised and the identification and practicalities of minimizing impacts. The trials have improved the understanding of methods for muddy dredged material by the parties involved that may lead to increased opportunities in the future. The UK Environment Agency has recently contracted HR Wallingford to undertake a 5-year monitoring program. This includes managed retreat sites and beneficial use of muddy material and should enable a more comprehensive level of monitoring to be undertaken. How beneficial different schemes are is still open to question.

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Selection of Wetland Sites for Reservoir Dredging Materials at Charles Mill Lake of Ohio

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ABSTRACT: Sediment deposition of Charles Mill Lake in Ohio has gradually reduced the effectiveness of reservoir operation over the years. It affects flood control and natural resources preservation including recreation, navigation, and water quality. The channel-bed survey of the reservoir was conducted with a global positioning system by the U.S. Army Corps of Engineers in the summer of 1998. The original reservoir and channel bed elevations were digitized at Ohio University. Both surveying and digitizing results were analyzed using a geographic information system (GIS). The accumulation of sediment deposits over the years, associated depths, and their geographic distributions were shown by GIS images. Major deposits were found along the mainstream of the original channel bed. Sediment sampling was conducted in summer 1998 for assessing the dredging program. The analysis of sampled sediments was done based on grain sizes, material grading, and soil uniformity using the geographic information system. It was found that there is a minimum percentage of gravel in the composition of sediment deposits. There are two main apparent locations of gravel settlement. The uniformity and gradation shown as images provide the geographical distribution of deposits, by which a working program for selecting disposal sites was developed in terms of prioritization. Two locations in the reservoir are selected for dredging material disposal by forming wetlands.

Key words: wetlands restoration, GIS, beneficial use, Charles Mill Lake, OH

RESERVOIR SEDIMENTATION

Sediment particles settle if the densities of particles are greater than that of water. The motion of this settling process is essentially involved with three forces, namely, the particle weight, W , the buoyancy force, F_b , and the drag force, F_d . When the particle reaches a constant velocity in the falling process, the net force is equal to zero, *i.e.*,

$$W - F_b - F_d = 0 \quad (1)$$

Let ρ_w be the density of water, D be the diameter of the falling particle, and μ be the dynamic

viscosity of water, then the Reynolds number, R_e , can be expressed as

$$R_e = \frac{\rho_w U D}{\mu} \quad (2)$$

Based on the Stokes law, if the Reynolds number is smaller than one, the drag force, F_d , can be estimated by (Streeter and Wylie, 1985)

$$F_d = \left(\frac{24}{R_e} \right) \left(\frac{\rho_w U^2}{2} \right) \left(\frac{\pi D^2}{4} \right) = 3\pi \mu U D, \quad (3)$$

where U is the settling velocity. Let ρ_s be the density of the falling particle, then Equ. 1 can be rewritten as

$$\rho_s g \left(\frac{4}{3} \right) \pi \left(\frac{D}{2} \right)^3 - \rho_w g \left(\frac{4}{3} \right) \pi \left(\frac{D}{2} \right)^3 - 3\pi \mu U D = 0, \quad (4)$$

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where g is the gravitational acceleration. Equ. 4 can be rearranged to result in an expression for the settling velocity as follows:

$$U = \frac{(\rho_s - \rho_w)gD^2}{18\mu} \quad (5)$$

The settling of a sediment particle depends mainly upon the density and diameter of the particle in a given water body based on Equ. 5. Particles may not be spherical, but Stokes' law can still give a good representation of the settling velocity. The settling velocity of a particle increases linearly with an increase of particle diameter. This has an implication on the sizes of sediment settling at the bottom of a reservoir or river. Flow turbulence may also affect the particle deposit. If the velocity is constant and fluctuations in the current's turbulence are small, the sediment deposits will be well graded (Trash, 1950). Sediment particles that are small enough to stay suspended will do so, while the larger particles fall out. On the other hand, large turbulence fluctuations in the current will carry a good range of particles that the sediment deposits will not be well graded. Therefore, sediment deposits can be predictable in a calm reservoir; the coarser sediment particles will be deposited near the entrance stream and finer materials will settle near the dam. The flow velocity decreases and results in finer material deposits as it gets closer to the dam. The depth of the sediment would generally be the greatest near the dam (Annandale, 1987).

BACKGROUND INFORMATION

Charles Mill Lake is on the edge of the glaciated region of Ohio. The reservoir has a shallow slope while it resides in several valleys so that it has an irregular shape. It is located four miles east of Mansfield, Ohio in Richland and Ashland counties. The inflow is mainly from the Black Fork Creek on the north of the lake. The water from the lake ultimately discharges to the Ohio River via the Muskingum River. The dam holding Charles Mill Lake was constructed in 1935 for the purpose of flood control. The Muskingum Watershed Conservancy District (MWCD) owns the lake and surrounding land and is responsible for the conservation management and recreational activities. The

dam is owned and operated by the U.S. Army Corps of Engineers. Reports have been made that the sediment deposition in the lake is gradually filling the lake. Residents in the surrounding areas and users of the lake have complained about poor navigability. In addition, the reservoir has reduced its effectiveness in controlling floods.

The man-made lake contains three natural lakes, Mifflin, Bell, and Mud, which existed before the dam was built. It also includes fourteen islands. The average depth of the lake has decreased by about one foot in 63 years. It means a decrease of about 20% of the volume of the lake. The watershed draining into Charles Mill Lake is 217 square miles. Table 1 lists facts about Charles Mill Lake and its watershed.

Table 1. Facts of Charles Mill Lake and the corresponding watershed.

Lake Length	20,700 feet	6,300 meters
Lake Breadth	6,200 feet	1,900 meters
Original Average Depth	5 feet	1.5 meters
Current Average Depth	4 feet	1.2 meters
Maximum Depth	34 feet	10.4 meters
Original Volume	11,369 acre-feet	14,034,230 km ³
Current Volume	8,129 acre-feet	10,034,678 km ³
Water Surface Area (normal pool)	1,339.5 acres	5.42 km ²
Shoreline Length	34 miles	53.5 km
Lake Elevation (normal pool)	997.1 feet (MSL)	304.0 meters
Lake Elevation (spill way)	1020.0 feet (MSL)	311.0 meters
Watershed Area	217 mile ²	562 km ²

SAMPLING AND ANALYSIS

Digitized topography and hydrography of the studied area were downloaded from the Geographic Information System Support Center, Ohio Department of Administrative Services and converted for use in the ArcView GIS. This data were 1:24,000 scale Digital Line Graphs. An original topographic map of the land, before the dam was built, was obtained and digitized. Once the map was digitized, the elevation point data were interpolated to create a continuous grid and a raster image as shown in Figure 1a. The recent topographic survey of Charles Mill Lake was obtained from the Army Corps of Engineers. The survey

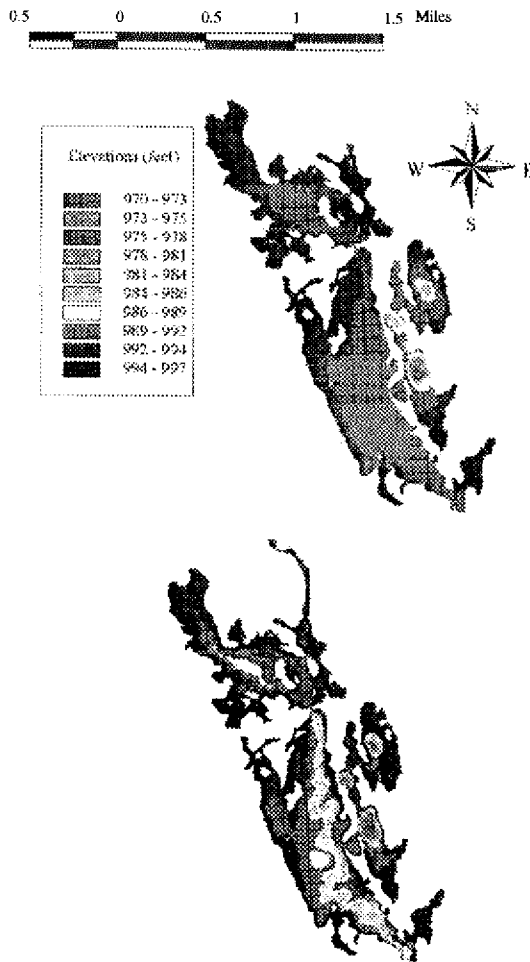


Figure 1. Topographical maps of Charles Mill Lake, in 1998 (above) and in 1934 (below).

was done in 1998 with cooperation with the MWCD using a Global Positioning System (GPS) and sounding equipment. These data points were also interpolated to create a raster image as shown in Figure 1 (top). The analysis of these two topographic images indicates that most of the sediment deposits has been located in the main channel, especially in the north section of the lake.

Based on the above result, the sampling locations were chosen to best represent the lake and sediment deposits. Figure 2 shows the distribution of the sampling location in the Charles Mill Lake. The sampling was taken from each location in July of 1998. Samples were retrieved with a gravity corer that could collect a core two feet long and three inches in diameter. Each sample was described in the field book, and the location was

taken down on the map and with a GPS. The description included the sample number, color, general soil classification, location, length of core, and time taken. Each sample was bagged and marked with identification for laboratory testing and analysis.

Moisture content testing and mechanical sieve analysis was conducted for each sample. The results were input into the associated coordinates along with the sample's general description. The data were further analyzed by a spline interpolation method to obtain a spatial distribution (Mitus and Mitsova, 1988). The particle-size distribution curve was developed for all samples. From the curves the D_{10} , D_{30} , D_{50} , D_{60} , and D_{90} values were interpolated and used for data points at the respective sampling locations. The D_{10} is the particle diameter that corresponds to 10% finer on the particle-size distribution curve. In other words, 90% of the particles are larger than the D_{10} value. The particle-size distribution curves were further used to determine the percentages of four classified materials, namely, gravel, coarse sand, fine sand, and silt/clay. It is noted that the total of these four percentages should be equal to one. The size of the soil in each class is listed in Table 2.

Table 2. Soil classification by particle sizes.

Soil Classification	Minimum Size (inches)	Maximum Size (inches)
Gravel	0.0787	-
Coarse Sand	0.0157	0.0787
Fine Sand	0.00295	0.0157
Silt/Clay	0.00000	0.00295

RESULTS

Sampling results are analyzed by the spline method. The analysis using the spline method imposes that the surface must exactly pass through the sampling locations during the spatial interpolation. In addition, the cumulative sum of the squares of the second derivative terms taken over each location on the surface must be a minimum. The spline method fits a mathematical function to a specified number of points, while passing through the sampling locations. It is assumed that the

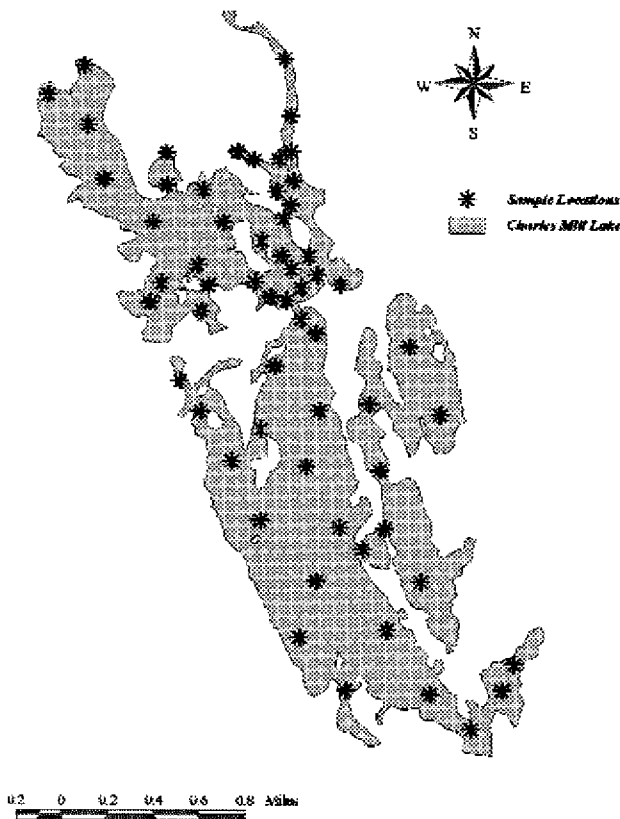


Figure 2. Sample point locations in Charles Mill Lake.

sediment deposits are continuous and have only moderate variations between sampling locations. The method worked reasonably well to interpolate sampled data smoothly.

The four classified sediment deposits are assumed geographically referenced variables. The interpolation using the spline method was conducted for each soil class resulting in a set of grid values that can be expressed as an image. Figure 3 is an example of gravel image that shows the geographical distribution of gravel deposit in the reservoir. It can be seen that two locations in the main channel have the high percentage of gravel deposit. One of the locations is the downstream of a highway bridge and likely has a high velocity. It is noted that the percentage addition of the four classes should be equal to one at any given location based on the defined classification. The spline method resulted in 5% error for only 2.6% of the grid analyzed; only 0.4% of the grid contained more than 10% error.

It is found that the sediment deposit in the lake contains only a small portion of gravel, about

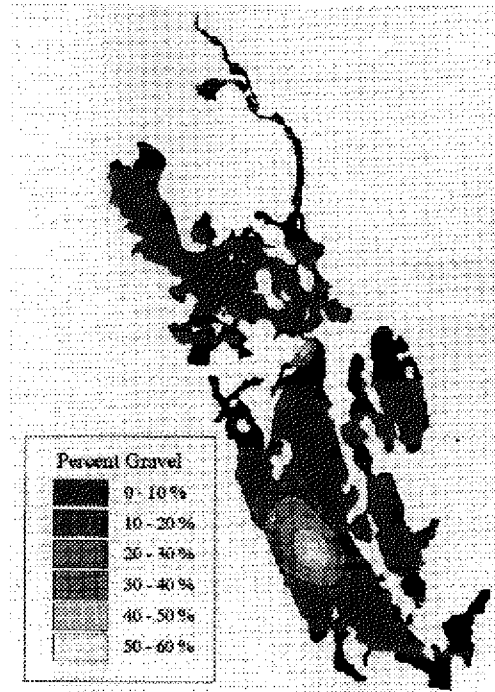


Figure 3. Percent gravel, based on the spline method of interpolation.

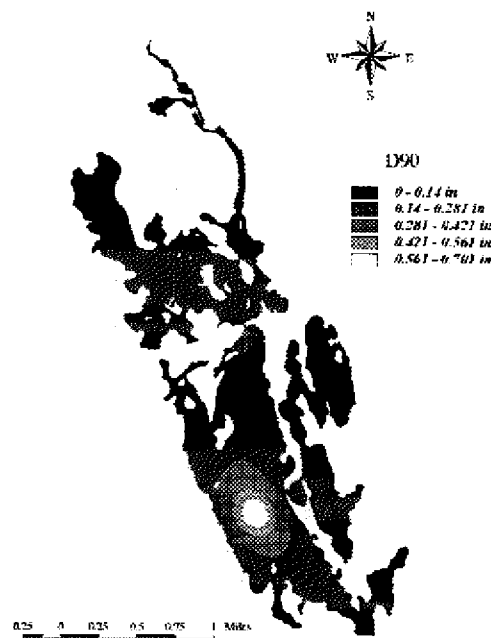


Figure 4. Diameter corresponding to 90% fines in the particle size distribution.

4.4%. Since the gradient of the stream is small, the flow is moderate and is not able to carry suspended gravel to the reservoir. The maximum percentage of gravel is about 50% near the bridge and in the southwest side of the lake. The bridge constricts

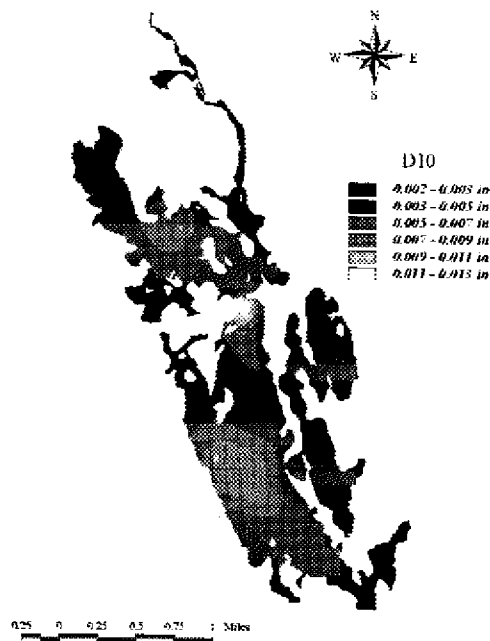


Figure 5. Diameter corresponding to 10% fines in the particle size distribution.

the only connection from the north section to the south section of the lake and causes the downstream scouring. The smaller particles are eroded, the larger particles remain. The average D_{90} for the sediment is 0.070 inches, where the D_{90} for downstream of the bridge is 0.30 inches as seen in Figure 4.

On the other hand, the effective size or average D_{10} for the sediment deposits is 0.0046 inches. The sediment deposits of smallest effective size are located near the entrance of the Black Fork Creek (see Figure 5). This may be due to the velocity decrease before the flow entering the lake. Once the flow enters the lake, the water becomes calm because of the constriction. The effective size increases after the bridge constriction in the downstream end. The percent of silt and clay is the greatest near the entrance of the Black Fork Creek, around 20%. The percentage of silt and clay decreases near the dam, which is an unusual phenomenon against the general rule that the fine deposit is near the dam.

The uniformity coefficient, C_u , was used as a factor to further examine the composition of sampled sediment deposits (Braja, 1994). It is defined as:

$$C_c = \frac{D_{30}^2}{D_{60}D_{10}} \quad (6)$$

where D_{60} and D_{10} are the diameters of particles obtained from the particle-size distribution curve for 60% and 10%, respectively.

The sediment deposit is usually gravelly if the uniformity coefficient is greater than four; it is sandy if the uniformity coefficient is greater than six. The main sandy area is in the middle of the southern section of the lake. Most of the sediment qualifies as nonuniform since its uniformity coefficient is less than four.

The coefficient of gradation, C_g , is used to determine how varied particles of sediment deposits are graded (Braja, 1994). It is defined as

$$C_u = \frac{D_{60}}{D_{10}} \quad (7)$$

where D_{30} , D_{60} , and D_{10} are the diameters of particles obtained from the particle-size distribution curve for 30%, 60%, and 10%, respectively. When the coefficient of gradation is between one and three, the sediment deposits are considered well graded. It is found that the area upstream of the highway bridge is not well graded, but the area downstream of the bridge is well graded.

The thickness of sediment deposits in the lake over the 60-year period is dependent on the changing ground elevation, as depicted in Figure 1. The original channel in the southern section has the greatest depth of sediment. Because of the sedimentation, the bottom of the lake appears smooth and flat, most markedly along the original mainstem of the river and just upstream and downstream of a highway bridge.

CONCLUSIONS

It was found that the major sediment deposits in Charles Mill Lake are along the original mainstem of the river. There is a minimum percentage of gravel in the composition of sediment deposits, and the settlement of gravel is mainly located at two apparent areas as graphically shown in the analyzed result. The uniformity and gradation provide the geographical distribution of sediment deposits, by which locations for sediment disposal to form wetlands are selected for the dredging program.

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Innovative Erosion Control Involving the Beneficial Use of Dredged Material, Indigenous Vegetation and Landscaping along the Lake Erie Shoreline

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ABSTRACT: Current conventional methods used to retard shoreline erosion include the installation of breakwaters, groins, and jetties. Sand replenishment is often used in conjunction with these methods when shorelines are being extended or restored. These techniques, though often functional, are costly and can detract from the natural environment.

This paper describes an innovative erosion protection project at Presque Isle State Park. This low cost, innovative demonstration project minimized erosion in the lesser energy zone of Misery Bay in Presque Isle State Park by utilizing native plants, bioengineering, and non-conventional erosion practices. The project, funded with a matching grant from the Great Lakes Commission, was completed in the spring of 1999 and early indications are that it has the potential of serving as a model for other lesser energy zones of bays and inlets along the Great Lakes.

Key words: beneficial use, indigenous vegetation, cost-effective, Lake Erie, PA

INTRODUCTION²

Protection of recreational beaches along ocean coasts and inland lakes, bays, and inlets, as well as finding a beneficial use for dredged material has become a sensitive issue to a diverse public. It is often difficult to find a solution that makes good engineering sense while maintaining environmental responsibility.

Current conventional methods used to retard shoreline erosion include the installation of breakwaters, groins, and jetties. Sand replenishment is often used in conjunction with these methods when shorelines are being extended or restored. These techniques, though often functional, are

costly and can detract from the natural environment.

In the past, dredged material has been viewed as a "necessary evil" associated with overdevelopment of coastal areas. Through the years, hundreds of tons of sediment have been dredged each year for commercial and recreational purposes and subsequently discharged into land-based disposal facilities or into our oceans, estuaries, rivers and lakes. As the space for disposal facilities reaches capacity, and discharge into water bodies becomes more of an ecological concern, the problem arises as to what to do with this material.

The purpose of this presentation is to describe in detail how Presque Isle State Park, located along the shoreline of Lake Erie in Pennsylvania, implemented an innovative erosion protection project which also included the beneficial use of dredged material. This low cost, innovative demonstration project minimized erosion in the lesser energy zone of Misery Bay in Presque Isle State Park by utilizing native plants, bioengineering,

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dredged material, and non-conventional erosion practices. The project, funded with a matching grant from the Great Lakes Commission, was completed in the spring of 1999 and early indications are that it has the potential of serving as a model for other lesser energy zones of similar bays and inlets along the Great Lakes.

BACKGROUND

Presque Isle State Park is a 3,200-acre migrating sand spit that juts 7 miles into Lake Erie and is a major recreational landmark for approximately 4 million visitors each year. The park, a National Natural Designated Landmark, is particularly environmentally sensitive with its constantly evolving shoreline and the presence of numerous plants recognized as being of exceptional value.

Additionally, the Audubon Society rates Presque Isle as one of the top birding areas in the northeast.

Protection of the spit has been an ongoing process since 1828. Along the Lake Erie shoreline, a series of conventional erosion control techniques such as groins, bulkheads, seawalls, and beach nourishment have been used with varying success. Between 1989 and 1992, many of the previous structures were removed and 55 offshore rubble mound breakwaters were constructed. Since completion of the breakwater construction, shoreline maintenance has been limited to an annual beach nourishment program. Construction of the breakwaters has decreased sand purchased for annual nourishment by 75 percent, from approximately 302,000 cubic yards before breakwater installation to approximately 40,267 cubic yards after breakwater construction.

Since 1975, the beaches along the lakeside of the park have been annually nourished; nourishment amounts vary based on fluctuating lake levels and storm severity. The prevailing winds along the lake are from the west, and as a result, the beach sand is in continual motion as it moves in response to longshore transport. While most of this transient sand is redeposited in offshore bars in the lake, some of the sand (generally the finer material) is carried around the distal end of the spit into the back bay area. Accumulation of this fine-grained sand in the back bay area has been a continual problem as these shallow areas become choked with sediment. As a result, the park struggles with

the problem of dredging these areas and finding a suitable disposal option for the dredged material.

Presque Isle was officially designated a state park in 1921, and in 1993, a Resource Management Plan was developed in order to protect the park's ecosystem. Within the park's Resource Management Plan, much of Presque Isle was designated as either a low density or natural area. These areas are defined as places that exhibit significant natural processes and resources and where very little to no development of recreational facilities or infrastructure is to occur.

Historically, protection of the shoreline from erosion had been accomplished along the Presque Isle Bay side of the park by utilizing large stones to riprap the shoreline. Although this process was very effective in preventing shoreline erosion and was quite suitable in the more developed recreational areas of the park, this solution did not concur with the desired results and appearance specified by the Management Plan for the low density and natural areas.

As a result of the delicate ecosystem of the spit, specific erosion problems along the bay, and the development of a sand bar within the park's back bay area, the decision was made to seek funding to advance an innovative solution to these problems. With this goal in mind, the Department of Conservation and Natural Resources, Bureau of State Parks—Presque Isle State Park, in conjunction with the Presque Isle Partnership, secured funding via a matching grant from the Great Lakes Commission. The project coordinated efforts between state and federal government units, as well as private, non-profit volunteer organizations to design, implement, and provide construction services for the project. This project brought forward a concept that provided the park with the protection needed for the infrastructure as well as creating a shoreline appearance that resembled natural shorelines along environmentally sensitive areas of the park. Additionally, the project provided a beneficial use of dredged material from the back bay sand bar.

In order to realize the goals of the project, the decision was made that rather than solely utilize conventional riprap, the project would incorporate a combination of riprap as well as indigenous vegetation, bioengineering, dredged material, and innovative landscape architecture to retard

shoreline erosion along a heavily used multi-purpose trail. Completion of this project has provided valuable information to other parks and recreational facilities in the Great Lakes area (especially along bay inlet areas) who are also faced with the challenges of minimizing erosion and sedimentation as well as finding a beneficial use for dredged material.

PROBLEM AREAS

There are numerous recreational features within the park. One of these is a 9.6-mile multi-purpose trail. This trail, designated as a National Recreation Trail, begins at the park entrance and completes a 13.5-mile loop throughout the park. This is the most popular trail within the park, and is heavily used by bicyclists, joggers, roller bladers, and is wheelchair accessible. Because of its popularity, protection of the trail from erosion is paramount.

A portion of this trail lies along the southern shoreline of the peninsula within Presque Isle Bay, Misery Bay, Marina Lake, and Thompson Bay; this area had been exhibiting significant erosion. Since this area was adjacent to Presque Isle's ecological reservation area, the standard riprap remedy was not appropriate because it did not match the park's designated management prescriptions.

Another popular tourist attraction is the Perry Monument, dedicated to Commodore Perry. The area surrounding the monument, located along Misery Bay, receives widespread use for shoreline fishing as well as the launching of recreational boats. Although wave energy along the shoreline of Presque Isle Bay is less active than along the lakeshore, fluctuating water levels and currents caused a significant sand bar to develop off the northeast tip of Perry Monument. The sand bar measured approximately 300 feet long by 25 feet wide by 5 feet deep (1,600 cubic yards) and severely restricted recreational boat usage. Removal of the sand bar was essential to preserve the recreational activities at the monument.

A small portion of this sand undoubtedly was the beach sand along the Lake Erie side of the spit. Since the finer materials are the first to erode, as may be expected in this back bay area where wave energy is less, this sand was of a smaller grain size than the beach sand. (Median grain size of the nourished beach sand was 2.0 millimeters, while

the grain size of the dredged material was 0.85 millimeters.) The probable source for the remainder of this sand was the erosion of the shoreline around Misery Bay. Historical photos of this area show that the east shoreline of Misery Bay has eroded several hundred feet since the late 1800's. Suitable disposal of this sand would be difficult because of its susceptibility to erosion no matter where it would be placed. Rather than follow the standard disposal options of this dredged material, the park wanted to find a constructive use for this sand.

There had also been some public concern brought to park management that recent amphibian research identified that riprapped shorelines may be causing a decline in turtle populations throughout the Erie area (but not specifically at Presque Isle State Park). The park does have a significant turtle population (9 different species, one of which, the Blandings turtle is listed in Pennsylvania as a species of special concern) and the shoreline along Misery Bay has been observed as a significant nesting area for the common snapping turtle. With this information in mind, it was determined that an alternative to riprap would be beneficial to the park's turtle population.

PROJECT DESCRIPTION

Figure 1 illustrates a cross-section of the project area. The first phase of the project was to remove some of the sand from Perry Monument. After passing the mandated state tests for disposal of dredged material, and in accordance with all applicable permits and regulations, approximately 1,200 cubic yards of material from the sand bar was dredged and placed in a staging area within the park so it could naturally dewater. The remaining sand was then graded to provide a suitable launch/mooring area for canoes and shallow boats.

The next phase involved the creation of a stabilized area on the backside of Misery Bay where the multi-purpose trail is adjacent to an ecologically sensitive area of the park. In this area, significant erosion had occurred, to the point that water was only 10 to 15 feet from the trail. Initially, the project proposed to install 4 to 10 inch-sized riprap (R-4) approximately 25 to 30 feet from the existing shoreline.

However, based on design criteria for the worst case scenario for wave height, which in this area

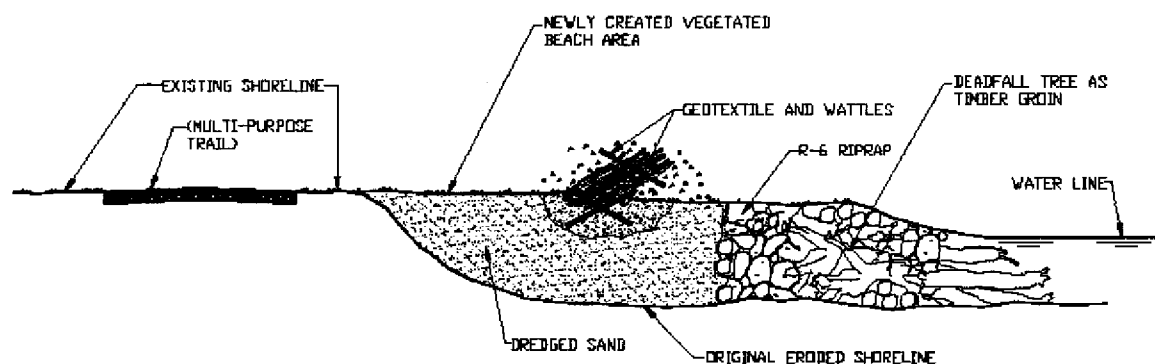


Figure 1. A cross section of the Misery Bay project area.

would be two to three feet, the decision was made to place 12 to 24 inch-sized riprap (R-6) offshore; it was felt that R-6 riprap would better protection for the shoreline. Placement of the R-6 riprap, which was below the water line, created an artificial stone shoreline that protected the multi-purpose trail by functioning as an erosion/wave energy dissipater.

Once the rock was in place, the third phase began. In this phase, the park placed the dewatered dredged material (sand) over the newly placed riprap, creating a higher elevation dune line. This subsequently provided a buffer of approximately 25 - 30 feet between the water and the trail. Next, to enhance the "natural" appearance of the shoreline, randomly spaced downed trees and stumps from the park (10 to 36 inches in diameter), minus the limbs, were used as timber groins. To function as groins, the tree root bases were anchored behind the riprap in the fill, and the trunks extended out past the riprap and into the water, also serving as sediment catch basins.

After the fill had been placed and prior to planting, the decision was made to use geotextile (comprised of coconut fiber cured to aid in longevity) in conjunction with wattles (poles interwoven with slender branches) in order to augment the vegetative plant rooting and further stabilize the fine-grained dredged sand. The geotextile woven material is biodegradable, but the plants should be well established before it decomposes.

Within the fill material, several trenches, parallel to the shoreline, were dug. First, the geotextile was laid in the trench, and then the wattles were

placed on top – end-to-end and parallel to the shoreline, approximately at the average high water mark. The geotextile was then rolled back over the wattles and staked with live saplings of dogwood, willow, redbud, and buttonbush. The wattles and geotextile were then further secured by placing sand on top; the sand helped to anchor the entire apparatus against the wind. The geotextile and wattles provided extra erosion protection to the shore zone area, as well as ensuring a stabilized area in the fine-grained sand for plant rooting.

Prior to planting of the indigenous vegetation, plant community goals were established to ensure that the plants would thrive in the newly created environment. The plant community goals were developed by reviewing historical records of plant community structure in that area, consulting local and regional plant experts, and considering wildlife uses of the site. After the goals were recognized, a vegetative planting plan was prepared. Final preparation of the site prior to planting included the addition of topsoil to the upper layer of sand, and shaping of the dune line.

The final phase was the vegetative planting. For this phase, local sources of plant material within the park were identified for transplanting on the dune. These included beach grass, Indian grass, switchgrass, choke cherry, bayberry, and black oak. Additionally, driftwood from local sources was collected and was dispersed in the restored area to provide shelter for the young seedlings and soil/litter organisms. Local sources of emergent wetland plants were located, and these were then transplanted into shallow water below the wattle line.

Transplanted aquatic plants included species that enhanced the establishment of desirable native emergent communities. These species, such as bur-reed, duck potato, three-square, and soft-stem bulrush were also beneficial to waterfowl.

After the native species were established, invasive species, targeted in the Presque Isle Partnership report, were mechanically removed as they were encountered throughout the restored areas. Herbicides were applied as necessary to eliminate invasive species that could not be controlled by mechanical means. The final objective was to achieve at least 50% vegetative cover in both the shoreline and dune habitats – this goal has been achieved.

The completion of the project, which included the construction of an off-shore “toe slope”, timber groins, breakwaters, and dune line, combined with the planting of native vegetation and the beneficial use of dredged material, has greatly reduced erosion and has provided protection for the heavily used multi-purpose trail.

Additionally, the newly created shoreline, adjacent to the park’s ecological reservation area, is home to several species of turtles. The project afforded the park an opportunity to develop a gentle sloping sand plain type shoreline conducive to turtle migration and nesting.

CONCLUSION

The dual goal of the project was to combine the beneficial use of dredged material, indigenous plants, and landscaping to reduce sediment loading into Lake Erie, and to protect the recreational aspects of Presque Isle State Park.

The completed project has resulted in several additional acres of stabilized vegetation and has decreased soil and subsequent nutrient runoff from entering Lake Erie. The amount of material removed from the Perry Monument sand bar has facilitated recreational boat usage and shoreline fishing in this area. In addition, turtles have nested and they have been observed travelling along the restored shoreline areas of the project.

The placement of deadfall trees and roots as groin structures and sediment catch basins along the project at Misery Bay have provided excellent resting habitat for the numerous waterfowl species

that make Presque Isle their home and migratory stopover location. Hundreds of ducks and geese can be seen at various times of the year resting on or near these structures.

The native plantings of wattles and live stakes provide for shoreline protection by way of their roots, and also serve as food sources and habitat for several hundred of the park’s avian species. This also provides the visual landscape to the project that matches the Management Plan directive to conserve natural qualities throughout Presque Isle State Park.

Through the years, conventional erosion protection techniques at Presque Isle State Park have been both costly and inappropriate for natural area management. Conversely, this economical project with a total cost of \$33,000 has provided a natural and aesthetic alternative to conventional shoreline erosion protection, has provided a beneficial use for dredged material, and has provided an area for turtle migration and egg hatching. While remaining within standard bureaucratic financial constraints, the project affords a valuable example to other parks and recreational facilities along the Great Lakes faced with the challenge of minimizing erosion while maintaining a natural appearance, and finding a beneficial use for dredged material.

Decontamination and Beneficial Use of Dredged Materials

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ABSTRACT: Our group is leading a large-scale demonstration of dredged material decontamination technologies for the New York/New Jersey Harbor. The goal of the project is to assemble a complete system for economic transformation of contaminated dredged material into an environmentally-benign material used in the manufacture of a variety of beneficial use products. This requires the integration of scientific, engineering, business, and policy issues on matters that include basic knowledge of sediment properties, contaminant distribution visualization, sediment toxicity, dredging and dewatering techniques, decontamination technologies, and product manufacturing technologies and marketing. A summary of the present status of the system demonstrations including the use of both existing and new manufacturing facilities is given here. These decontamination systems should serve as a model for use in dredged material management plans of regions other than NY/NJ Harbor, such as Long Island Sound, where new approaches to the handling of contaminated sediments are desirable.

Key words: beneficial use, decontamination, New York/New Jersey Harbor

PROJECT DESCRIPTION

The goal of this project is to develop sediment decontamination facilities that can be used to handle a substantial fraction (ca. 375,000 m³/year) of the

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dredged material produced in the Port of New York/ New Jersey as a result of dredging for maintenance of navigational channels and for environmental purposes. To this end, more than 10 different technologies for decontamination have been carried through bench-, pilot-, and large-scale tests. In addition, consideration has been given to the basic science needed to understand contamination transport, decontamination chemistry, biotoxicity, and beneficial use. Such information is needed for making dredging decisions, assessing environmental and human health effects, and optimizing several types of decontamination technologies.

Summaries of project work have been given in a number of publications and reports (Jones *et al.*, 2000; 1999a & b; 1998a & b; 1997; Ma *et al.*, 1998; Stern *et al.*, 1998a,b & c). Publications and technical reports on project demonstrations can be found on our project web site (<http://www.wrdad-con.bnl.gov>).

During 2001, a project using a sediment/soil washing technique will be implemented in cooperation with BioGenesis and BASF. The work will combine remediation of a BASF brownfield site together with construction of a BioGenesis sediment processing facility with a throughput of 180,000 m³/year on that site. Another 2001 project using a high-temperature process developed by the Gas Technology Institute/Endesco will be constructed on a second site. It will be able to process about 22,500 m³/year of as-dredged sediment with moisture content of 60%.

Sediment cleaning is a multistep process beginning with dredging the sediment, cleaning, and ending with disposal of the clean material. The beneficial use of the material is a key factor in determining the success of the decontamination process. The beneficial use products from the facilities will be manufactured soil and cement which can be sold to generate a revenue stream to bring tipping fees into a range that is economically feasible for the Port of NY/NJ.

DEMONSTRATION PROJECTS

We have taken a very broad view of the need for decontamination technologies in the NY/NJ Harbor region. The two obvious requirements for any technology are that they have affordable treatment costs and no adverse environmental impacts.

The technologies were selected from responses to several requests for proposals. The work was structured as a series of step-by-step demonstrations proceeding from small-scale to large-scale. At the end of each step, the technologies that would move forward in the demonstration process were selected. A list of all the technology organizations participating in the demonstrations is given in Table 1.

Table 1. Technology organizations participating in the dredged material decontamination demonstrations.

	Gas Technology Institute/Endesco
Biogenesis/Weston	U. S. ACE Waterways Experiment Station
Marcor	International Technologies
Metcalf & Eddy	NUI Environmental
JCI/Ucycle	BEM Systems
BioSafe	Westinghouse Plasma Systems/Global Plasma Systems

SCIENCE

Pathways for contaminant accumulation and transport include complicated physical and chemical processes that depend on sediment properties on a grain-size scale. These processes depend on sediment properties such as grain size, specific surface area, mineral composition, and contaminant chemistry. Information of this type is needed not only on a macroscopic scale, but also on the grain-size scale. This type of data is necessary for improved modeling of transport and fate of the contaminants and also to help in optimizing physico-chemical approaches to sediment decontamination. We have conducted microscale survey experiments using high-intensity synchrotron x-ray sources at the Brookhaven National Synchrotron Light Source (NSLS) (<http://nslsweb.nsls.bnl.gov>) and the European Synchrotron Radiation Facility (ESRF) (<http://www.esrf.fr>). The techniques that have been applied include x-ray fluorescence, x-ray radiography, x-ray absorption near-edge spectroscopy (XANES), Fourier transform infrared spectroscopy, and absorption and fluorescent computed microtomography. The spatial resolutions used generally range from about 0.0001 mm to 0.015 mm.

A computed microtomogram measured for a

sediment sample is shown in Figure 1 as an example of this approach. The experiment gives a three-dimensional view of the packing of sediment particles and shows the pore space and the connectivity of the material. Data of this nature will serve as the foundation for a microscopic model of contaminant transport. Other experiments show the distribution of organic and inorganic compounds on the sediment grains. These data can be used as the basis for designing water jets used for mechanical cleaning of particle surfaces and for choosing the best approaches for use of chemical removal of contaminants by chelators and surfactants.

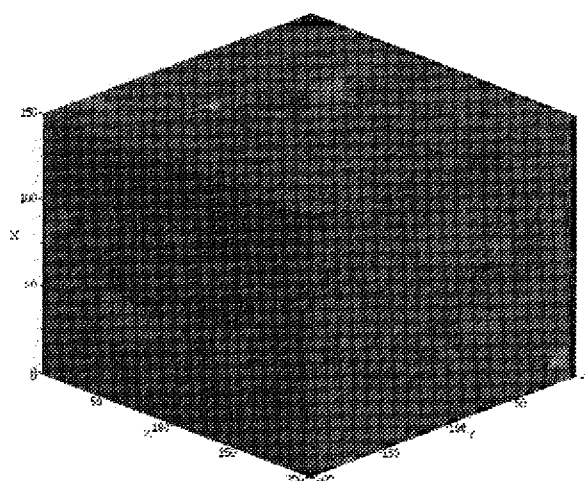


Figure 1. Computed microtomogram showing grains and pore spaces in Newtown Creek sediments. The color scale shows the variation of the x-ray absorption coefficients in the different particles with the lighter areas being the most strongly absorbing. The dark spots are indicative of pore space. The linear pixel dimension is 0.0068 mm.

PHYSICO-CHEMICAL SEDIMENT PROPERTIES

The macroscopic properties, as well as the microscopic properties, of the sediments from the Port of NY/NJ are of great importance for understanding contaminant transport, selection and application of decontamination technologies, and evaluation of beneficial use avenues. For example, a simple measurement of the grain-size distribution is crucial for design of protocols for applying the BioGenesis sediment washing technology. As shown in Figure 2, the sediments in the Port are very fine grained and thus present a challenge for the application of a washing technology. X-ray

diffraction is used for determination of major oxide composition. This information is needed so that in a cement production process compounds can be added for optimal cement composition. Thermal desorption measurements are helpful in giving qualitative information on the concentrations of the organic materials found in the sediments.

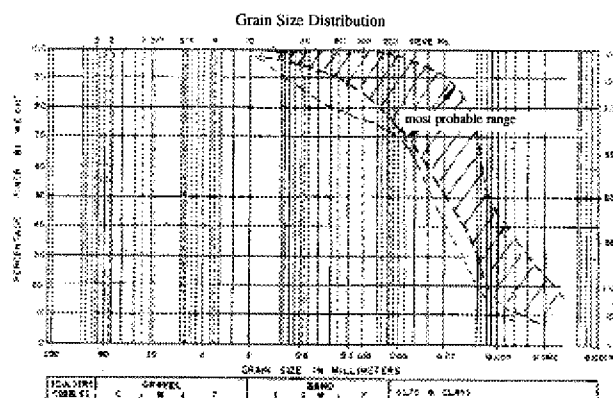


Figure 2. Distributions of grain sizes found for typical dredged material from NY/NJ Harbor. (Courtesy of The Port Authority of New York & New Jersey)

TECHNOLOGY TREATMENT EFFECTIVENESS

Treatment effectiveness, as determined in the bench-scale tests, is shown for seven different technologies in Figure 3. The three at the right are high temperature approaches and are the most effective in destruction of organic compounds. The results for BioGenesis/Weston and the Gas Technology Institute/Endesco projects are numbered 1 and 6, respectively. See the descriptions of their continuing demonstrations below.

BIOGENESIS/WESTON SEDIMENT/SOIL WASHING DEMONSTRATION, KEARNY, NJ

The BioGenesis/Weston demonstration uses a combination of a high-pressure water jet, surfactants, and chelators to remove metals and organic materials from contaminated sediments and soils. It is an advantageous approach since the capital costs are comparatively modest and the throughput is high. The equipment is modular so that the total processing capacity can be readily increased. A schematic diagram of the process is shown in Figure 4. The demonstration unit will process

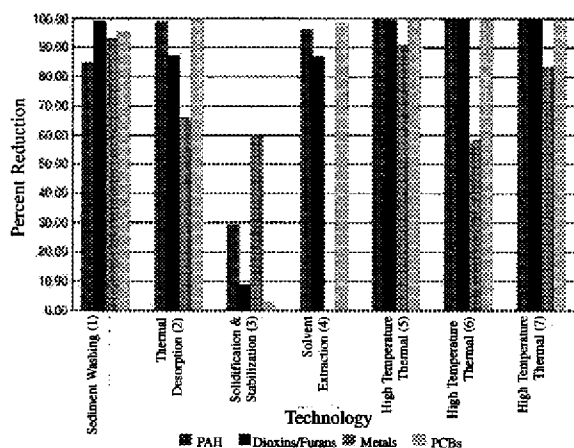


Figure 3. Treatment effectiveness for bench-scale tests of seven different technologies.

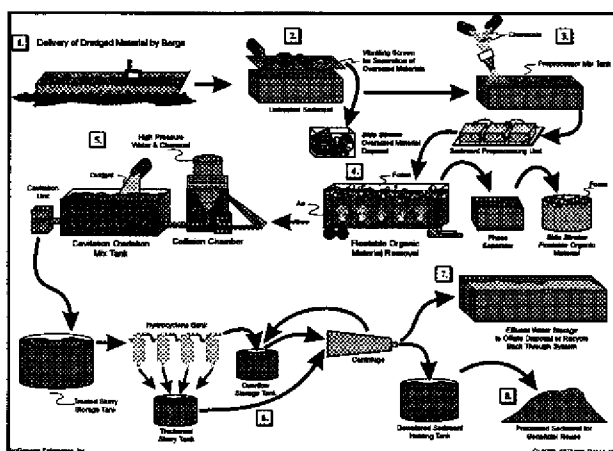


Figure 4. A schematic diagram of the BioGenesis Enterprises sediment washing process.

Cement-LockSM Technology

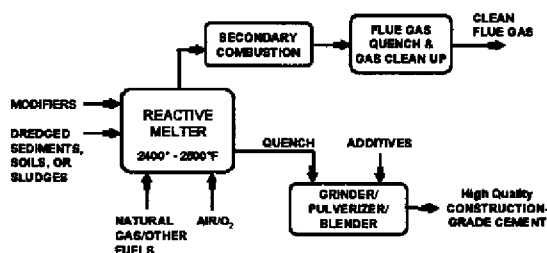


Figure 5. A simplified diagram of the GTI/Endesco process for producing cement from dredged material. Modifiers are added to adjust the composition to yield the best cement composition.

180,000 m³/year. The decontamination work will be combined with remediation of a brownfield on the site and capping of contaminated sediment along the shoreline in order to produce a wildlife refuge, ecological, education center, and nature viewing area. This will be done as a public-private partnership involving local, state, and federal agencies, elected officials, and community groups working with the commercial groups of BioGenesis and the BASF Corporation. BASF is the owner of the site and has been instrumental in developing the concept.

GAS TECHNOLOGY INSTITUTE/ENDESCO ROTARY KILN DEMONSTRATION, KEARNY, NJ

The Gas Technology Institute demonstration will be implemented at a brownfield site on the west bank of the Hackensack River in Kearny, NJ. A rotary kiln (1400 °C) will be used to melt a mixture of sediments and modifiers to form a cement matrix of calcium-alumino silicates. The melt is then pulverized and mixed with additives to make construction-grade cement. Organic compounds are destroyed and metals are locked in the product matrix. Exhaust gases are cleaned up to ensure no organic compounds are emitted and to remove volatile metals. A simplified diagram of the process is shown in Figure 5. The construction-grade cement produced has compressive strength properties that exceed ASTM standards for Portland cement. The metal concentrations are similar to those found in commercially available cements. The material also passes standard leaching tests for metal removal.

Production of a commercial-grade product was demonstrated in the initial bench- and pilot-scale tests. Effective beneficial use is dependent on the existence of a suitable market. Available data show the demand for cement increasing by about 800,000 metric tons per year. Thus, production of cement from sediment could help to reduce the need for added imports to meet demand. Marketing and distribution of the cement can be accomplished either by direct sales to end-users (e.g., ready-mix plants, construction companies) or to an existing cement manufacturer. The high value of the product will help to make this process competitive with other dredged material management options.

FUTURE DIRECTIONS

It is clear that our most pressing near-term task is to bring the two large-scale demonstrations of GTI/Endesco and BioGenesis Enterprises to completion. One point to be considered in so doing is to solve the problem of matching high-peak volumes of dredged material generated in the dredging process to the capacities of the decontamination facilities. This can be done by inserting the equivalent of a buffer tank at the entrance to the processing treatment train. In practice, we propose to build, as a buffer tank, a small, contained disposal facility with a capacity of about 180,000 to 375,000 m³ to serve as the input source of the dredged material to the BioGenesis Enterprises treatment facility.

Work on other tasks is also planned:

- The feasibility of using additional technologies for sediment processing needs to be investigated at the bench- and pilot-scale levels.
- The results of our demonstrations need to be implemented in other regions. Extending infant collaborations in the Great Lakes and Puget Sound regions can do this.
- There are several barriers to technology implementation (regulatory, contracting) that need to be overcome. One very important barrier is the reluctance of many agencies to let long-term contracts for processing dredged material. This makes raising private financing for facility capital construction costs difficult or impossible.

It is important to extend the types of beneficial use products that can be produced from sediments.

This is of importance if we are to be able to view dredged material as representing a natural resource for the manufacture of a variety of products.

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Engineering Issues for the Development of Wetland Cells at Poplar Island Restoration Project, Chesapeake Bay

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ABSTRACT: Poplar Island is located in Chesapeake Bay, east of Washington D.C. The restoration of Poplar Island to the approximate 1847 footprint of 1,100 acres, using clean dredged material was conceived by the Maryland Port Administration (MPA) in cooperation with the U.S. Army Corps of Engineers, Baltimore District (CENAB), Maryland Environmental Service (MES), state agencies, federal agencies and private organizations. The restored island will be used as a placement site for dredged material from the outer approach channels to the Port of Baltimore. With a projected site capacity of about 40 million cubic yards, the operational life of the Poplar Island site is estimated to be approximately 15 to 20 years. This paper addresses the key engineering issues related to development of the wetland cells at Poplar Island, and outlines the methodology used to solve the issues.

Key words: wetland restoration, beneficial use, Chesapeake Bay, hydraulic models, engineering design

INTRODUCTION

Poplar Island is located in Chesapeake Bay about 32 miles southeast of Baltimore-Washington International Airport and 35 miles east of Washington D.C. The Poplar Island restoration project was recommended by Governor Schaefer's Task Force and involves restoration of habitat lost through the erosion of Poplar Island. The project involves creation of aquatic, inter-tidal wetland, and upland habitat for fish and wildlife. This beneficial use project also helps maintain more than 125 miles of federal navigation channels that provide access to the Port of Baltimore. In connection with the restoration plan for Poplar Island, U.S. Army Corps of Engineers, Baltimore District (CENAB), Maryland Port Administration (MPA) and Maryland Environmental Service (MES) are preparing a Site Development Plan (SDP) for managing the filling and the development of wetland cells. Gahagan & Bryant Associates, Inc. (GBA) was retained by CENAB and MPA through

MES for assistance in site development.

In April 1997, MPA entered into a Project Cooperation Agreement (PCA) with CENAB to construct the Poplar Island Restoration Project under the provisions of Section 204 of the Water Resources Development Act (WRDA) of 1992. Due to funding and schedule limitations, the project was divided into two phases: (i) Phase I - 638 acres, and (ii) Phase II - 504 acres (see Figure 1). CENAB awarded the Phase I contract to Kiewit Construction Company, in January 1998, for a total price of \$45.4 million. Phase I construction was completed in March 2000. The Phase II contract was awarded to Tidewater Construction Company, in April 2000, for a total price of \$37.6 million. Phase II is currently under construction, and development of the Phase I wetland cells is currently being planned and implemented.

PHASE I CONSTRUCTION

Water depths in the project area vary from 0.6 to 4 m (~2 to 12 ft) below project datum, Mean

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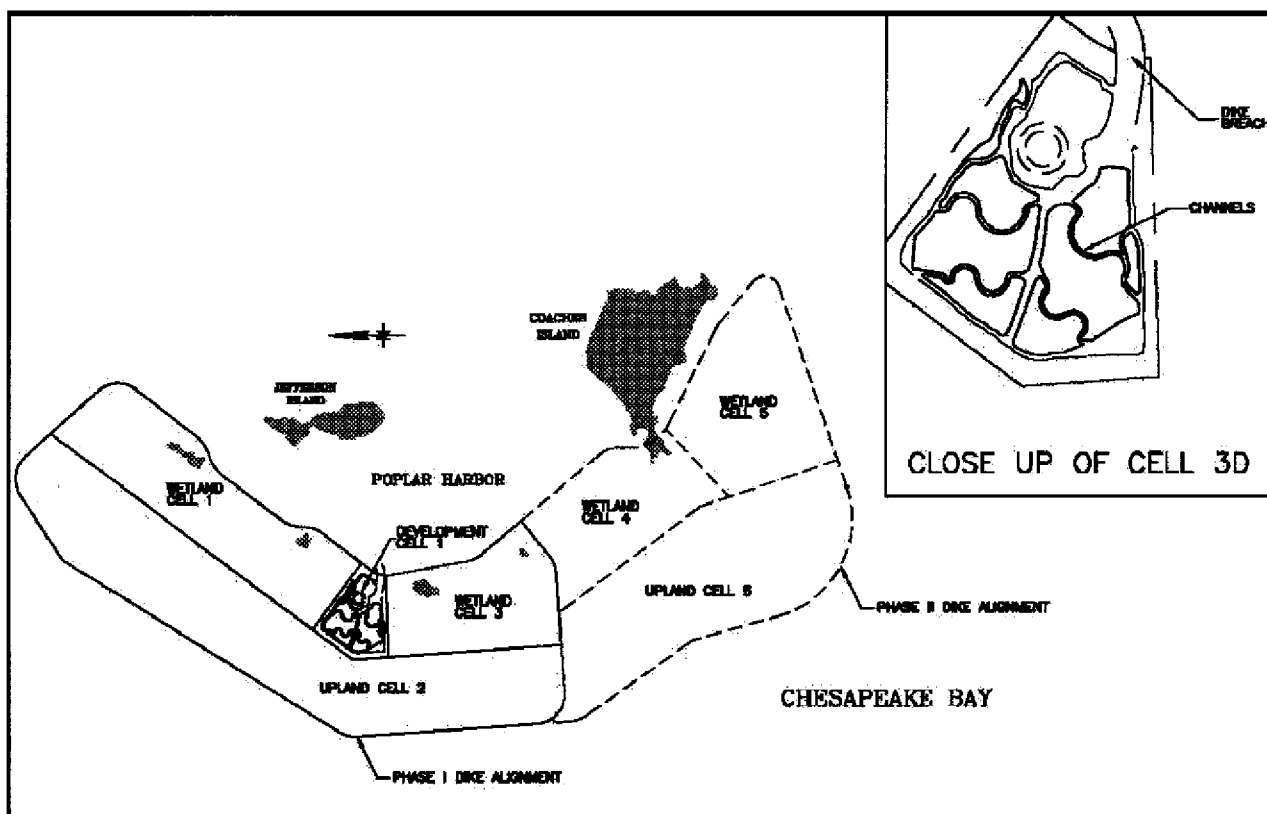


Figure 1. Layout of the Poplar Island Restoration Project.

Lower Low Water (MLLW). The mean tidal range at the site is approximately 0.4 m (~1.2 ft), and the mean high spring water level is 0.7 m (~2.5 ft) above MLLW. During a 100-year storm, the water levels could rise as much as 2 m (~7 ft) above MLLW (GBA and M&N, 1996).

Phase I construction consisted of a containment dike system (25,000 ft of perimeter dikes and 13,000 ft of interior dikes), including exterior stone toe dike, sand core, slope underlayer and slope armor stone. The sand core material was excavated from subaqueous borrow pit areas on site. The various stone products were mined in a quarry in West Virginia, railed to Baltimore and then barged to the project site. Phase I dike construction included about 500,000 tons of stone and 3.5 million cubic yards (mcy) of sand.

ENGINEERING ISSUES

There are several engineering issues with regard to the successful development of wetland cells at Poplar Island: (a) How much dredged material will be placed in each cell to obtain the

final desired wetland elevation? (b) What is the rate and final completion of dredged material consolidation? (c) How will multiple dredging projects (with variable consolidation characteristics) affect the consolidation process? (d) What will be the specific inflow sequence for material placement at the site? (e) How will the material be dewatered and managed to meet the final wetland objectives? (f) How many breaches will be required and what are the dimensions? (g) What will be the internal channel layout and geometry for flushing the wetland cells? (h) When is the right time to plant and or seed the cells? (i) What is the criterion and how will vegetation success be monitored? and (j) What are the construction and cost considerations? In order to address these issues, the "development cell" concept was introduced to "test" the engineering design variables prior to full-scale site development.

THE "DEVELOPMENT CELL" CONCEPT

In order to study the various factors that could potentially influence the successful development of

wetland cells at Poplar Island, it was decided to construct a 33-acre wetland "development cell" (see Figure 1). A cross dike (Cell 3D cross dike) is being constructed across wetland cell 3 to aid in formation of the development cell 3D. Spillways will be used to convey ponded water pumped into the cell during placement operations. It is envisioned that approximately 0.25 mcy of dredged material will be placed in Cell 3D to construct the wetland. There will be a 2-month hiatus after placement of the first 0.15 mcy of material, to accelerate consolidation. Following the 2-month hiatus, the remaining 0.10 mcy of material will be placed in the cell. Once the material is 90% consolidated, indicating the achievement of a stable surficial condition, interior channels will be constructed.

There will be three primary marsh zones in Cell 3D with specific MLLW reference elevations: (i) The mudflat (elevation 0.0 to +0.3); (ii) The low marsh (elevation +0.3 to +1.8); and (iii) The high marsh (elevation +1.8 to +2.2). Tidal channels in cell 3D will consist of primary channels (35-50 ft wide and 3 ft deep), and several secondary (branch) channels (15-25 ft wide and 3 ft deep) for providing circulation. In addition, cell 3D has a bird habitat island with a surrounding 50 ft wide and 5 ft deep moat channel. Once the dredged material has consolidated and stabilized, the eastern dike of the development cell will be breached to form a 100 ft wide opening to facilitate tidal flushing.

FIELD DATA COLLECTION

A three phased field data collection program is being planned for Poplar Island wetland development: (i) Reference Marsh Sampling – this involves detailed sampling of several reference marshes in the area to define the elevation ranges of the various marsh zones (mudflats, low and high marsh), (ii) Hydraulics Sampling – this involves sampling of natural channel geometry and velocity distribution, in connection with wind and tidal measurements at select locations, (iii) Development Cell (3D) Sampling – this refers to detailed measurement of the geotechnical, hydraulic, and biologic (vegetation) performance of the development cell using periodic cell surveys,

geotechnical sampling, channel velocity measurements, tidal elevation monitoring, and vegetation monitoring. Note that final details on the field data collection plan are being reviewed and no decision has been as to the actual plan to be implemented on site.

MODELING OF SEDIMENT CONSOLIDATION

During the process of dredging materials from the navigation channels, the *in-situ* density (hence void ratio) of the material is altered, resulting in an overall increase in void ratio. As the material is placed at the site (typically using a hydraulic unloader), the addition of water causes the material to expand or "bulk" even further. Following placement, the height of the dredged material is reduced by four mechanisms: (a) sedimentation, (b) primary consolidation, (c) secondary compression, and (d) desiccation. Of these, the sedimentation process is usually complete within a few days after initial material placement and so it is not critical to the long-term material elevation prediction. Settlement due to secondary compression is often quite small when compared to the primary settlement and it is often neglected. Primary settlement and desiccation are therefore the key factors to be determined. Given the minimal tidal amplitude at the Poplar Island site, the vegetation is expected to have a very narrow range of tolerance to changes in elevations. Therefore, it is critical to accurately predict, plan, design and monitor for the proper wetland material elevations.

It was decided to use the U.S. Army Corps of Engineers' Waterways Experiment Station (WES) computer model, PSDDF (Primary consolidation, Secondary compression and Desiccation of Dredged Fill) to predict the "bulking" and "shrinkage" characteristics of the dredged material placed within Poplar Island cells. PSDDF simulates the primary consolidation, secondary compression and desiccation processes in fine-grained soils using the finite strain theory of consolidation and an empirical desiccation model. Over 70 model runs were performed for the Poplar Island cells. At each run location, monthly inflow thickness of dredged material fill was computed for model input using the expected volume of material to be placed at each cell. The modeling plan was selected to

include simulations for a range of placement rates and lift thickness for the various cells (ranging from 3 ft to as much as 27 ft).

Model results indicate that settlements for the 3 ft lift varied from 0.6 to 1 ft for the various cells (based on area and rate of fill). It took approximately 1.5 years for the 3 ft lift to fully consolidate and stabilize (GBA, 1999). For the 6 ft lift, the settlements varied from 2 to 2.5 ft for various cells. The time to stabilize for the 6 ft lift was nearly 3.5 years. For larger lift thickness, the settlement and the time to stabilize increased to approximately 50% of the lift thickness and more than 4 years. The model will be refined during and after filling, using actual observations collected as part of the field-monitoring program.

MODELING OF CELL ELEVATIONS

Using the results from the PSDDF model, a Digital Terrain Model (DTM) was developed for Poplar Island wetland cells. The DTM for Poplar Island represents a spatial view of material elevations at the site at various time periods subsequent to placement. The DTM was generated using estimated material consolidation at known grid points. The DTM is an ideal tool to plan inflow locations to obtain specific final material contours at various locations within the cells. The methodology for developing the digital terrain model consisted of the following steps: (i) Review of PSDDF Model Results; (ii) Establishment of the decant surface for the first iteration; (iii) Establishment of the consolidated cell surface at six months, one year, two years and four years after decant (time=0); and (iv) Multiple iterations to hit target elevations for the various marsh zones. The results of the DTM model were then used to layout the tidal channels for flushing.

DESIGN OF MARSH CHANNELS

This process consisted of the following steps: (i) Determine biological bench mark elevations for the marsh zones, (ii) Review reference marshes with similar amplitudes to determine the channel density to inter-tidal marsh plain area. Determine the width of the marsh plain that can be effectively flushed using empirical relationships; (iii) Estimate

the volume of water that has to be freely exchanged during a tidal cycle to produce an unrestricted channel geometry, especially at the breach openings. Develop conceptual layout of the channels; (iv) Evaluate channel layout and flushing using appropriate numerical models. Refine channel geometries, alignments and control structures, as needed; and (v) Design and construct the test cell using the recommended channel layout scheme and monitor real-time results. Collect data from the development cell 3D (such as flow, velocity, tidal amplitude, sediment deposition and consolidation data) for further refinement of the model.

HYDRAULIC MODELING OF DEVELOPMENT CELL 3D

The Surface Water Modeling System (SMS) available from Brigham Young University (BYU) was used to simulate the site hydraulics at Poplar Island. SMS is an update of the U.S. Army Corps of Engineers computer program TABS, which consists of submodels for simulating the 2-D hydrodynamics, transport and sedimentation problems in rivers, bays and estuaries. Basically, SMS consists of two submodels - (a) the RMA-2, the hydrodynamics model, and (b) the SED-2D, the sediment transport model. RMA-2 uses a finite element grid to generate flow velocities (magnitude and direction) in the model domain. It is a two-dimensional depth averaged finite element hydrodynamic model that computes the water surface elevations and velocity vectors for subcritical, free-surface flow in two dimensions. RMA-2 computes a finite element solution of the Navier-Stokes equations for turbulent flows. Friction is computed using Manning's or Chezy equation and turbulence is defined by eddy viscosity coefficients. The program can simulate both steady and unsteady conditions.

Model runs were completed for these conditions in the development cell: (i) Tidal forcing only; (ii) Tidal forcing combined with an upland flow of 1 cfs, (iii) Tidal forcing combined with an upland flow of 5 cfs, (iv) Tidal forcing combined with an upland flow of 10 cfs, (v) Tidal forcing combined with an upland flow of 20 cfs, (vi) Tidal forcing combined with an upland flow of 40 cfs, (vii) Tidal forcing combined with an upland flow of 80 cfs, and (viii) Tidal forcing combined with an

upland flow of 160 cfs. Model results for the tide only case indicated that the marsh was getting wet and dry in direct correlation to the tidal cycle (GBA, 2000). No chronic erosion areas were visible. The one aspect to note is the low velocities along the breach and the channels suggest that the marsh system may not provide adequate natural flushing for sedimentation that occurs in the cell. This effect will be evaluated during the sediment transport-modeling phase.

For model runs with upland flow from spillway discharge activities, it was assumed that the flow would be constant over the time period being modeled. The results indicated that as the upland flow increases, the area that is prone to potential erosion increases. It follows that some upland discharge controls (with a maximum stipulated discharge velocity) along with lining (riprap) of the pond area fronting the discharge may need to be implemented. A comparison of water balance in the cell indicated that the tidal flow was not overwhelmed by the upland discharge until flows exceeded about 40 to 80 cfs. The model will be revised once field observations are available from post-construction monitoring.

VEGETATION MANAGEMENT ANALYSIS

Key elements of the vegetation management study are summarized. (i) On-site nursery: The performance of the on-site nursery areas constructed in Phase I was evaluated through a site visit and it was found that an off-site nursery location is preferable. Potential concerns included erosion, herbivory, inadequate planting grades, disease and/or vandalism. (ii) Off-site nursery: Essentially, a commercial nursery is set up to produce the maximum amount of plant material in the smallest area possible. In addition, installation labor would be saved if the materials were propagated in "field friendly" type of stock (for example, eliminating digging and separating the *Spartina alterniflora* and *S. patens* rhizome mat by initially propagating in easily replantable peat pots). It was recommended that nursery-grown material (containerized especially), is the best method, should planting be employed. Seeding *Spartina alterniflora* is also an economical way to proceed. (iii) Reference Marshes: A series of reference marshes were used

for developing biological benchmarks for the site. The reference sites were chosen based on the condition that such sites should be as close both in distance and physical parameters as possible to the site. (iv) Future plans: These include development of a timeline for planting vegetation in the development cell, vegetation monitoring in cell 3D, development of a methodology for vegetation establishment and monitoring for the remaining wetland cells.

SUMMARY

Key engineering aspects affecting the development of wetland cells for the Poplar Island Restoration Project were listed in this paper. Methodologies that are planned for addressing these issues were also listed. The planning, design and implementation strategies for Poplar Island may serve as useful guidelines for future marsh projects.

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CHAPTER 4

Risk Assessment

A Review of the Risk Assessment Methods used to Establish Permitting Criteria for Open Ocean Disposal of Dredged NY/NJ Harbor Sediments

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ABSTRACT: For sediments in the New York/New Jersey Harbor, the U.S. Army Corps of Engineers (USACE) employs a framework of sediment quality evaluation to determine whether contaminated sediments are suitable for open ocean disposal (*i.e.*, do not pose a health risk) or whether more extensive and costly disposal methods are required. The degree to which chemicals can bioaccumulate from sediments into benthic invertebrates is a key determinant in the permitting decision. The maximally “acceptable” levels of bioaccumulation (bioaccumulation criteria) have been developed over a period of several years, using a variety of different methods. We reviewed the technical bases of these criteria and found that, while some values can be considered “risk-based”, others are based on historical background concentrations, U.S. Food and Drug Administration action levels, limits of detection, and other non-“risk-based” methodologies. Hence, the degree of health protection in the criteria varies considerably amongst the chemicals. Also, consistent application of the “risk-based” methods to all chemicals yields very different bioaccumulation criteria for some constituents. We reviewed the decisions of 15 permit applications and found that the use of “risk-based” values for all chemicals would have yielded very different disposal decisions. These findings illustrate the need for a consistent, valid, and risk-based approach for contaminated sediment management decisions.

Key words: sediment, bioaccumulation, open ocean disposal, risk assessment, New York/New Jersey Harbor

INTRODUCTION

Approximately 4 million cubic yards of sediment are dredged annually from the Port of New York and New Jersey (Port) in order to maintain navigable channels. For years, the dredged sediments were placed in an offshore area now referred to as the Historic Area Remediation Site (HARS) (40 CFR Sections 228.15(d)(6)). Currently, only dredged material deemed to be relatively “uncontaminated” (designated as

“Category I” sediments) can be placed at the HARS. Dredged materials that do not meet Category I criteria must be handled using other methods such as placement in confined disposal facilities; sediment decontamination, reduction, and/or minimization; and beneficial uses such as habitat creation or restoration.

In order to assess disposal options for the dredged sediments, the New York District of the Corps and the U.S. Environmental Protection Agency (USEPA) Region 2 have employed regional and national guidance that mandate tiered testing of dredged material (USEPA and USACE,

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1991; USACE and USEPA, 1992; USEPA and USACE, 1998). Because sediments throughout the Port typically contain elevated levels of a number of potentially bioaccumulative and toxic chemicals, a bioaccumulation test is almost always required as part of the permit application. The New York District of the Corps and USEPA Region 2 specify that the burrowing polychaete *Nereis virens* and the deposit-feeding mollusk *Macoma* sp. be used for bioaccumulation testing (USACE and USEPA, 1992). The results of the bioaccumulation tests are almost always cited in the permit decisions as the critical factor in determining the disposal option for the dredged sediments.

The maximally "acceptable" levels of chemical bioaccumulation (bioaccumulation criteria) used to evaluate the results of these assays, and therefore the ultimate fate of the sediments, have been developed over several years with a variety of disparate methods. The purpose of this analysis was to assess the degree of consistency in the methods used to derive the criteria, and to determine whether a single, refined approach might yield significantly different values. We also reviewed 15 permitting decisions over the last 10 years and determined whether significantly different disposal decisions would have been reached using a single set of consistently derived criteria.

REVIEW OF BIOACCUMULATION CRITERIA

USFDA ACTION LEVELS

U.S. Food and Drug Administration (USFDA) Action Levels have been used as bioaccumulation criteria for aldrin, dieldrin, chlordane, heptachlor, heptachlor epoxide, total polychlorinated biphenyls (PCBs), and mercury. The USFDA employs Action Levels to remove food products from the market. These values, which are based on human health and economic considerations, are typically much higher than chemical concentrations derived strictly from health-based concerns. In addition, humans do not typically consume the organisms used in the bioaccumulation tests. Furthermore, the Action Levels do not account for the ecological effects of contaminants on benthic organisms or their predators. Therefore, the relevance and degree of protection offered by the Action Levels

is unclear. As shown in Table 1, Action Levels are still the only bioaccumulation criteria available for chlordane, heptachlor, and heptachlor epoxide.

REGIONAL MATRIX LEVELS

Tissue concentrations referred to as "regional matrix levels" were established in 1981 for cadmium, mercury, total DDT, and total PCBs. The matrix levels for cadmium and mercury were the mean chemical body burden in certain invertebrate species in the New York Bight Apex, as measured in lobster, quahog, clams, and rock crab in studies published from 1972 to 1980 (USACE, 1981). Since these particular invertebrates are not the test species used in the bioaccumulation tests, and because the "background" data are up to 30 years old, the relevance and degree of health protection offered by these regional matrix criteria is unclear. As shown in Table 1, the regional matrix value is still the only bioaccumulation criterion for total DDT.

To derive the regional matrix level for total DDT, DDT body burdens in benthic invertebrates were estimated using measured water column concentrations and a bioconcentration factor (BCF) for fish tissues. The total DDT water column concentration was based on two sea-surface data points of DDT metabolites collected in the 1970s and the BCF was estimated based on a review of literature available at that time (USACE, 1981). There are several apparent shortcomings associated with this criterion: 1) similar to the cadmium and mercury criteria, it is based solely on "background" measurements, 2) it is based on data and assumptions that are close to 30 years old, 3) it is derived from only 2 data points, and 4) it presumes that bioaccumulation from water to fish tissues is equivalent to bioaccumulation into benthic invertebrates. Similarly, regional matrix values for total PCBs in benthic invertebrates were based on chemical levels measured in the water column in the late 1970s and fish and macro-invertebrate BCFs available at the time. Hence, the total PCB criterion suffers from the same shortcomings identified above.

REGIONAL DIOXIN VALUES

The regional matrix TCDD criterion of 1 ppt is based on an instrumental limit of detection (USACE

and USEPA, 1992). The 4.5 ppt total toxic equivalence (TEQ) criterion for the sum of all the non-TCDD 2,3,7,8-substituted dibenzofurans is also based on limits of detection, and was derived by multiplying half of the limits of detection for each congener by their respective toxic equivalency factors (TEFs) and summing the products (USEPA and USACE, 1998). These instrument-driven criteria are clearly not health-based, and the degree of health protection offered by these values is unclear.

RISK-BASED CRITERIA

Two types of "risk-based criteria" were derived for some chemicals in 1997 (Table 1). These criteria

are based on background tissue concentrations and/or estimated ecological and human health effect levels. For the latter category (effects-based criteria) the chronic water quality criteria (WQC) were multiplied by empirically determined BCFs to derive criteria protective of ecological effects (USEPA and USACE, 1998). However, the BCFs that the Corps and USEPA Region 2 used for aldrin, dieldrin, chlordane, endosulfan, and 1,4-dichlorobenzene are based on fish rather than the benthic organisms used in the bioaccumulation tests. For total polycyclic aromatic hydrocarbons (PAH), the Critical Body Residue (CBR) approach was used to calculate a bioaccumulation criterion based on ecological effects. However, as with the

Table 1. Bioaccumulation criteria values used to evaluate dredged material disposal option.

		FDA Action Level	Regional Matrix ^a	Risk-Based Bioaccumulation Criteria				
				Background - <i>Macoma</i>	Background - <i>Nereis</i>	Ecological	Effects	Human Health-Cancer
PAHs	Acenaphthene	(µg/kg)		8.1				8775000
	Acridene			10		3750		43605000
	Benzo(a)anthracene						20000 *	
	Benzo(a)pyrene			24.2		8000	2000	
	Benzo(b)fluoranthene						20000 *	
	Benzo(k)fluoranthene						20000 *	
	Chrysene						20000 *	
	Dibenz(a,h)anthracene						2000 *	
	Fluoranthene			43.8				5805000
	Fluorene			7.4				5805000
	Indeno(1,2,3-cd)pyrene						20000 *	
	Phenanthrene			32.7				43605000
	Pyrene			51.3				4387000
	Total PAHs			432.7		40000	2000	
Pesticides	Aldrin	(µg/kg)	300	0.9		299	33	167
	Dieldrin		300			4.37	65	518
	α-Chlordane		300					
	Heptachlor		300					
	Heptachlor epoxide		300					
	Total Chlordane/Heptachlor					64 (57.6)	114	135
	Total Endosulfans					2.85		87000
	Total DDT		40			24.89	1584	2692
Total PCBs	(µg/kg)	2000	100, 400 ^b	106.6		717.98	269	188
1,4-Dichlorobenzene						11820	60000	
Metals	Arsenic	(mg/kg)				12.6		
	Cadmium		0.3	1.21		2.33		4.8
	Chromium (based on Cr VI)			1.28		11.8		73 (14.5)
	Chromium (based on Cr III)							22000
	Copper			5.58		9.6 (7.92)		540
	Lead			1.41		11.9 (11.34)		1.3
	Mercury	1	0.2	0.04				0.5
	Nickel			1.1		3.8		290
	Silver					1.4 (0.04)		73
	Zinc			11.5		1517 (1428.84)		4400
	TEQs (non 2,3,7,8-TCDD) ^c	(ng/kg)	1	1.73	2.5		3.5	
Dioxins			4.5		2.13			

- Values in plain text indicate criteria values provided in USEPA and ACE (1998).

- Bolded values are calculated using USEPA and USACE (1998) approach for chemicals that USEPA and USACE (1998) did not derive criteria.

- Values in parentheses indicate different criteria calculated using USEPA and ACE (1998) approach with current water quality criterion or human toxic potency values.

^aRegional dioxin level for dioxins.

^bRegional matrix values for total PCBs are 100 (clam) and 400 (worm).

^cDioxin TEFs taken from USEPA (1989).

^dWater quality criterion or human toxic potency values currently unavailable.

^eValue derived using USEPA (1993) PAH relative potency factors.

^fInorganic arsenic value in IRIS database not applicable.

chlorinated compounds mentioned above, a CBR for fish was used for total PAHs.

Bioaccumulation criteria for the protection of human health were based on estimates of fish/shellfish consumption using the USEPA default exposure methodology. Conservative exposure factors (70 kg body weight, 6.5 g/day consumption rate, and 70-year lifetime) were used in the calculation. Trophic transfer factors and a whole body/fillet ratio of 1.35 were applied to convert the "acceptable" fish and shellfish tissue levels to benthic invertebrate tissue concentrations (USEPA and USACE, 1998). A human health risk level of 10^{-4} (for carcinogenic risk) and a hazard quotient of 1 (for noncarcinogenic effects) were used as acceptable risk benchmarks. As with the ecological criteria, there is still a significant degree of uncertainty inherent in many of the values, because 1) the default whole body/fillet ratio of 1.35 is unlikely to be accurate for all chemicals in all edible species, and 2) the exposure estimates assume that an individual's lifetime diet of fish is derived only from fish that prey on benthic organisms at the HARS.

DEVELOPMENT OF CONSISTENT RISK-BASED BIOACCUMULATION CRITERIA

We used the USACE and USEPA 1998 methodology to update and/or derive "risk-based" effects-level ecological and human health bioaccumulation criteria for all chemicals listed in Table 1, using the most current EPA water quality and toxicity criteria. Risk-based ecological criteria were derived for three chemicals that previously did not have such values: total DDT (using the WQC for 4,4'-DDT), total PCBs (using the WQC for Aroclors), and cadmium. As shown in Table 1 (bolded values under "Risk-based Bioaccumulation Criteria / ecological effects" heading), the new values for cadmium and total PCBs were higher than the most stringent of the non risk-based values employed by USACE; for total DDT, the new risk-based value (24.09 ppb) was somewhat lower than the "Regional Matrix Value" of 40 ppb. For total Chlordane and Heptachlor, copper, lead, silver, and zinc, updated ecological values differ from the previous values due to updated WQC and/or BCF data. As shown in Table 1, (the numbers in parentheses are the updated values; chemicals with no

parenthetical values did not have updated WQC or BCFs.

In this analysis, human cancer-based bioaccumulation criteria are derived de novo for 9 chemicals: benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, indeno(1,2,3,-cd)pyrene, total DDT (using the cancer potency factor for 4,4'-DDT), total PCBs (using the cancer potency factor for Aroclor 1254), and 2,3,7,8-TCDD (cancer potency factor of 156,000 (mg/kg-day)⁻¹). The derivation for the six PAH compounds employed the benzo(a)pyrene cancer potency factor and USEPA's (1993) relative potency factors. The derivation of human non-cancer bioaccumulation criteria is based on the same exposure scenario, but reference doses and an acceptable hazard index of 1.0 are used. In this analysis, five new human non-cancer bioaccumulation criteria were derived, and one updated value was derived for chromium. The updated criterion for chromium is based on the reference dose of chromium (III) since it is the dominant chromium species in sediment.

As shown in Table 1, the 2,3,7,8-TCDD human cancer "risk-based" criterion of 3.5 ppt is over 3-fold higher than the 1 ppt limit of detection value that has been employed by USACE. For chromium, the updated human non-cancer criterion increased from 73 ppm to 22,000 ppm.

RE-EVALUATION OF DREDGING PERMITS USING NEW AND UPDATED BIOACCUMULATION CRITERIA

A sample of 15 dredging permits from the past 10 years were evaluated to determine whether permitting decisions might have had different outcomes if risk-based values for all chemicals had been used. In one permit involving dredging of 90,000-yds³ of sediment, bioaccumulation testing resulted in Category I status would have failed under the "risk-based" ecological screening values derived herein for copper and silver. Four permits (717,000-yds³ total) were classified as unsuitable for Category I disposal with 2,3,7,8-TCDD cited as the sole reason, or in combination with total DDT. However, none of these sediments exceeded the human health risk-based criteria for 2,3,7,8-TCDD calculated in this analysis. These permits, instead, exceed the risk-based screening values for other

chemicals such as total DDT, copper, silver, and PCBs. Two permits (150,000+ yds³) were assigned as having sediments ineligible for Category I disposal with 2,3,7,8-TCDD cited as the sole cause for rejection. However neither 2,3,7,8-TCDD nor any other chemical exceeded the risk-based criteria calculated in this analysis. Hence, these sediments would likely have been granted Category I status if risk-based criteria had been used for all chemicals.

CONCLUSION

The bioaccumulation criteria employed by USACE and USEPA Region 2 vary significantly in the relevance of their technical basis and degree of health protection. The USEPA/USACE "risk-based" bioaccumulation criteria appear to be the most relevant but they have been derived for only some chemicals. Many of the permitting decisions of the last ten years would have been significantly different if consistently derived, risk-based bioaccumulation criteria had been employed.

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Use of Sediment Toxicity Testing Methods to Evaluate Dredged Material Management Guidelines at Porto Marghera, Venice, Italy

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ABSTRACT: The current system of dredged material assessment/management at port facilities located at Porto Marghera in Venice, Italy is based on numerical sediment quality criteria. Dredged material is classified into one of three categories (A, B, or C) depending upon the concentrations of heavy metals, total PAHs, total PCBs and organochlorines. It is anticipated that future assessments of dredged material in Italy will likely use the Venetian numeric-based approach. To assess the potential implications of shifting from the current numeric-based approach to effects-based testing on dredged material management activities, a comparative evaluation was conducted between the Venetian numerical-based approach and the U.S. effects-based approach. Sediments representing each of the three dredged material management categories were collected from navigation channels within the Port of Venice. Sediment from an aquatic disposal site located in the Lagoon was collected as reference material. Sediments were analyzed for bulk sediment chemistry and evaluated using Tier III testing procedures described in the U.S. Testing Manual. Results of Tier III sediment toxicity and bioaccumulation testing were compared to the Venetian numeric-based approach. The degree of concordance between the numeric classification and the observed effects in each category of dredged material was difficult to ascertain because of the confounding influence of environmental factors, most notably ammonia. The resulting inconsistencies in the test results illustrate the caution that must be taken when relying solely on chemistry and test results for management decision-making. Further testing and evaluation is needed to fully understand the potential implications of an effects-based approach on future dredging and dredged material management in the Venice Lagoon.

Key words: sediment quality guidelines, Venice, effects-based testing, risk assessment

INTRODUCTION

Porto Marghera is located 4 km northwest of the historic city of Venice, Italy and adjacent to the city of Mestre (Figure 1). The Port of Venice located at Porto Marghera is the largest commercial shipping port in Italy and one of the largest ports in the Mediterranean Sea. Autorita Portuale di Venezia

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(referred hereafter as the Venice Port Authority) is responsible for maintaining the main navigation channel, Canale Malamocco Marghera, and other port navigation channels, to 12 m depths. The channels are dredged periodically and the material managed according to a three-tier numerical sediment classification scheme developed by the Ministry of the Environment (Ministero dell'Ambiente, 1993). Sediment is classified as either Class A, B, or C material based on the level of heavy metals, PAHs and organochlorine contamination. Class 'A' sediment is used for restoring lagoon salt marsh (barene); class 'B' sediment is managed in aquatic environments subject to certain management restrictions; and, class 'C' sediment is disposed in a confined disposal facility located at Isola delle Tresse, adjacent to the main navigation channel. Dredged material that exceeds class 'C' limits is removed from the Lagoon and handled at an upland disposal facility.

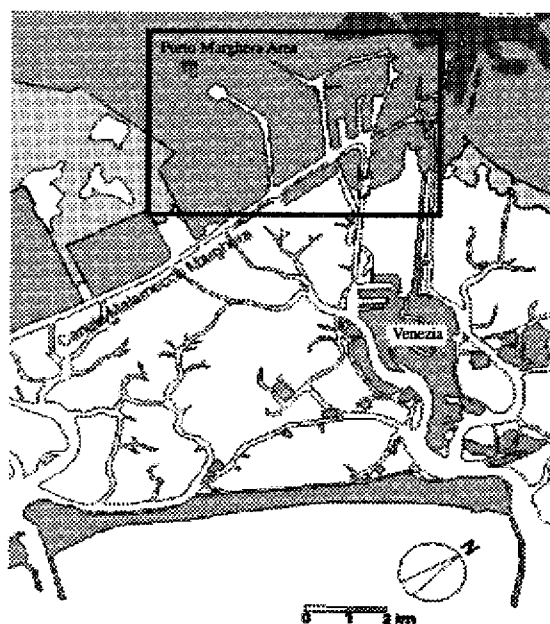


Figure 1. Location of Porto Marghera in the Venice Lagoon.

Sediment and biota monitoring studies conducted over the past five years indicate that the Venice Lagoon ecosystem has been adversely affected by eutrophication and chemical pollution, due predominantly to point and nonpoint discharges originating within the industrial district at Porto

Marghera (DiDomenico *et al.*, 1997; Fattore *et al.*, 1997; Marcomini *et al.*, 1997; Wenning *et al.*, 2000a). The results of an ecological risk assessment (ERA) by Wenning *et al.* (2000a) indicated that PCDD/F levels in Lagoon sediments were comparable to the levels found in undeveloped coastal environments. The results also indicated a limited potential for adverse effects on aquatic wildlife; however, contamination in the Lagoon was not homogenous. A "hot spot" was identified at Porto Marghera, where PCDD/F levels in sediment at a few locations approached the levels found in ports located elsewhere in Europe and in the United States.

The President of the Italian Council of Ministers has designated the Venice Port Authority and the Venetian Water Authority (Magistrato alle Acque di Venezia) as the institutions responsible for characterization and remediation of the sediment in navigation channels at Porto Marghera (Regione Veneto, 1999). In response to this requirement, the Venice Port Authority and Venetian Water Authority have initiated a series of sediment assessments, biological studies and engineering reviews to understand current environmental conditions and formulate an action plan to meet the Council's goals (APV, 1999; Della Sala *et al.*, 2000). As part of these efforts, a more comprehensive ERA than the previous screening-level assessment, which included food web modeling and sediment toxicity testing, was performed to evaluate the possible effects of different sediment management options on aquatic life in the Lagoon (Wenning *et al.*, 2000b).

The primary purpose of the sediment toxicity testing conducted as part of the comprehensive ERA was to evaluate the potential implications on future dredging and dredged material management activities in Venice Lagoon. This was done by comparing the current Venetian numerical-based approach with the effects-based approach developed for the regulatory evaluation of dredged material in the U.S. Selected sediments from navigation channels within Venice Lagoon were collected to be representative of the three dredged material management categories. Sediment was collected from a nearby aquatic disposal site for use as a reference material. Sediments were analyzed for bulk sediment chemistry and evaluated in

Table 1. Summary of PCDD, PCDF, PCB, DDT, hexachlorobenzene, and total organochlorine pesticide concentrations (ug/kg d.w.) in surficial sediment and dredged material collected from navigation channels at Porto Marghera, Venice, Italy.

Chemical *	No. Samples Analyzed	No. Samples > Detection Limit	Mean Concentration	95% UCL
Surface Sediment (0–50 cm)				
2,3,7,8-TCDD	30	23	1.23E-03	1.86E-03
Total PCDDs	33	19	0.37	0.58
Total PCDFs	33	19	1.76	2.57
2,3,7,8-TCDD TEQs	33	19	2.13	3.12
Total PCBs	132	132	5,370	7,420
Total DDT	37	9	2.57	2.84
Total OC Pesticides	32	28	661	896
Hexachlorobenzene	42	28	136	209
Dredged Material (0–3 m)				
2,3,7,8-TCDD	40	28	1.38E-03	2.13E-03
Total PCDDs	43	43	0.47	0.75
Total PCDFs	43	43	2.30	3.56
2,3,7,8-TCDD TEQs	43	43	2.77	4.30
Total PCBs	17	17	81.1	144
Total DDT	56	9	2.54	2.72
Total OC Pesticides	51	37	547	716
Hexachlorobenzene	48	46	125	190

*Total PCBs, PCDDs, and PCDFs are reported as 2,3,7,8-TCDD equivalents (TEQs) using Van den Berg *et al.* (1998) toxicity equivalent factors.

accordance with the Tier III testing procedures described in the U.S. Testing Manuals (USEPA/USACE, 1991, 1998). The results of Tier III sediment toxicity testing were compared to the classification of the material described by the Venetian numeric dredged material management standards. The degree of concordance between numeric classification and observed effects in each category of dredged material was examined in light of the potential implications for future dredging and dredged material management.

ENVIRONMENTAL DATA AND TOXICITY TESTING METHODS

A compilation of chemistry and physical measurements of navigation channel sediment was completed by the Venice Port Authority and the Venetian Water Authority in 1999. The data are summarized in Table 1 and Table 2. The sediment database currently consists of 306 records representing 196 sampling locations. Chemistry analyses were performed in various commercial and university laboratories using analytical procedures specified by the Ministry of the Environment (Ministero dell'Ambiente, 1993). Suspended particulate phase and solid phase sediment toxicity testing was conducted in accordance with the Tier

Table 2. Summary of metal concentrations (ug/kg d.w.) in surficial sediment and dredged material collected from navigation channels at Porto Marghera, Venice, Italy.

Chemical	No. Samples / > DL	Surface Sediment (0–50cm)		Dredged Material (0–3m)	
		Mean Concentration	95% UCL	Mean Concentration	95% UCL
Arsenic	140/140	4.76E+04	5.81E+04	5.67E+04	6.94E+04
Cadmium	142/133	1.63E+04	2.28E+04	1.96E+04	2.62E+04
Chromium	119/119	4.84E+04	5.41E+04	5.46E+04	6.45E+04
Copper	118/118	1.17E+05	1.37E+05	1.40E+05	1.79E+05
Lead	120/120	2.10E+05	2.53E+05	2.81E+05	3.69E+05
Manganese	26/26	5.89E+05	6.43E+05	7.49E+05	1.09E+06
Mercury	145/126	1.15E+04	1.50E+04	1.60E+04	2.11E+04
Nickel	114/114	2.60E+04	2.78E+04	3.14E+04	3.86E+04
Selenium	12/7	7.04E+03	1.50E+04	9.21E+03	1.76E+04
Tellurium	7/2	1.07E+03	1.85E+03	1.88E+03	4.14E+03
Thallium	7/5	2.71E+03	5.85E+03	3.88E+03	8.24E+03
Tin	7/7	1.29E+04	1.62E+04	2.35E+04	4.91E+04
Vanadium	9/9	6.52E+04	7.61E+04	7.13E+04	8.95E+04
Zinc	145/145	1.39E+06	1.74E+06	1.76E+06	2.26E+06

Table 3. ITM/OTM Tier III sediment toxicity test procedures used to evaluate Venice navigation channel sediments.

Test Type	Test Procedure	Interpretive Criteria	Reference
Suspended Particulate Phase (SPP)	48-hour echinoderm development with <i>S. purpuratus</i>	Comparison of factored LC50 or EC50 value (0.01 x LC50) to estimated SPP concentration at the edge of the mixing zone using the STFATE model	E 1563-98 (ASTM 1999) (USACE/USEPA, 1991, 1998)
	96-hour survival in <i>M. bahia</i>		E 1191-97 (ASTM 1999); (USACE/USEPA, 1991, 1998)
	96-hour survival in <i>M. beryllina</i>		(USACE/USEPA, 1991, 1998)
Solid Phase (SP)	10-day amphipod survival in <i>E. estuarius</i>	Comparison to survival in reference sediment exposed organisms	USEPA 1994; (USACE/USEPA, 1991, 1998)
	10-day polychaete survival in <i>N. arenaceo-dentata</i>		E 1611-94 (ASTM 1999) (USACE/USEPA, 1991, 1998)

III testing procedures described in the U.S. Testing Manuals (USEPA/USACE, 1991, 1998). A summary of the series of suspended and solid phase tests conducted on each representative class of navigation channel sediment is presented in Table 3.

RESULTS

CHEMISTRY ANALYSIS

A summary of the sediment chemistry results is presented in Table 4. Comparison of the measured chemical concentrations in sediment samples representing each of the three different classes

described in the current Venetian dredged material management guidelines indicated that the selected sediments provided a reasonable representation of the three classes of material. In both the reference and 'A' category sediments, the majority of measured contaminants were below the 'A' guideline values with the exception of mercury. In the 'B' sediment, most of the measured constituents were above 'A' but below 'B' guideline values. In the 'C' material, mercury was the only constituent exceeding the 'C' guideline value.

Comparison of chemical concentrations to Long *et al.* (1995) ER-M values (Table 5) showed an increasing trend (*i.e.*, reference < 'A' < 'B' < 'C') in both the SER-M quotient (ranging from 1.6 to 7.2) and the average ER-M quotient (ranging from 0.16 to 0.72) for the measured constituents.

Constituents consistently approaching or exceeding ER-M values in category 'B' and category 'C' sediment included mercury, zinc, and total PCBs.

Table 4. Classification of Contaminant levels in Venetian navigation channel sediment samples collected for Tier III testing using the Venetian Dredged Material Management Guidelines.

Chemical Units: mg/kg	Reference		A		B		C	
	Class	Value	Class	Value	Class	Value	Class	Value
Arsenic	A	10.2	A	3.8	B	15.4	A	12.8
Cadmium	A	<0.2	A	0.9	B	4.7	B	2.4
Chromium	A	18.9	A	13.5	A	17.9	A	13.7
Copper	A	14.3	A	25.4	B	48.2	B	52.7
Lead	A	14.5	A	30.7	B	98.7	B	64.4
Mercury	A	0.5	B	0.92	B	1.84	C	2.84
Nickel	A	20.9	A	13.6	A	17.5	A	26.8
Zinc	A	49	A	120	B	395	B	330
Total Hydrocarbons	A	12.2	A	10.6	B	59	B	191
Total PAHs	A	<0.020	A	0.398	B	2.061	B	7.358
Total PCBs	A	<0.020	A	<0.018	B	0.082	B	8.186
Chlorinated Pesticides	A	<0.001	A	<0.001	A	<0.001	A	<0.001

Table 5. Contaminant Concentrations in selected Venetian navigation channel sediments expressed as a percentage of Long *et al.* (1995) ER-M values.

Chemical	Reference		A		B		C	
	Class	% of ER-M Value	Class	% of ER-M Value	Class	% of ER-M Value	Class	% of ER-M Value
Arsenic	A	14.6%	A	12.6%	B	22.6%	A	18.3%
Cadmium	A	1.8%	A	9.4%	B	48.9%	B	25.6%
Chromium	A	5.1%	A	3.6%	A	4.8%	A	3.7%
Copper	A	5.3%	A	9.4%	B	18.2%	B	19.5%
Lead	A	6.7%	A	14.1%	B	45.3%	B	28.5%
Mercury	A	78.4%	B	128.6%	B	258.2%	C	371.8%
Nickel	A	46.5%	A	28.4%	A	33.9%	A	55.8%
Zinc	A	12.9%	A	28.3%	B	16.3%	B	82.7%
Total Hydrocarbons	A	NA	A	NA	B	NA	B	NA
Total PAHs	A	8.8%	A	8.9%	B	4.8%	B	16.4%
Total PCBs	A	5.8%	A	5.0%	B	51.1%	B	92.2%
Chlorinated Pesticides	A	NA	A	NA	A	NA	A	NA
Sum ER-M Q		1.61		2.48		5.94		7.15
Average ER-M Q		0.16		0.24		0.56		0.72

TIER III TOXICITY TESTING

Suspended particulate phase (SPP) tests showed significant effects relative to control in the 50% and 100% elutriate concentrations of category 'A' and 'B' sediments for all three test species evaluated in this study. The results for the minnow (*M. beryllina*) shown in Figure 2 were typical of those observed in tests involving mysid shrimp (*M. bahia*) and sea urchins (*S. purpuratus*). SPP tests conducted on category 'C' material did not show significant effects on the three test species. Comparison of initial measured total ammonia levels in the SPP tests with the reported no observable effect concentration (NOEC) for each of the test species evaluated suggested that the observed toxicity was most likely due to ammonia.

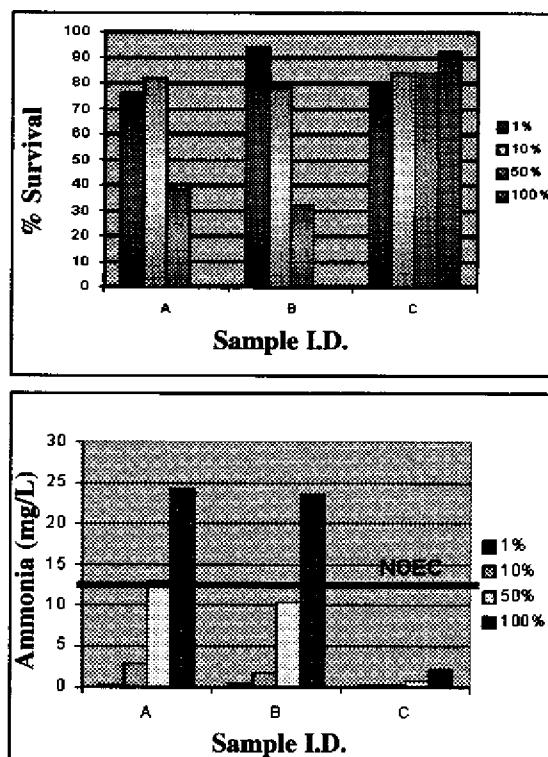
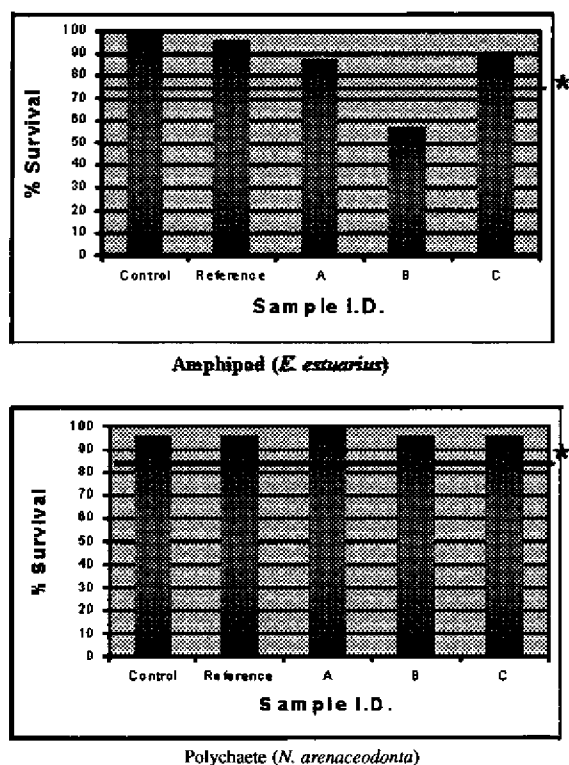


Figure 2. Results of the suspended particulate phase test and initial ammonia concentrations for the minnow (*M. beryllina*) exposed to three classes of Venetian navigation channel sediments.

The results of the solid phase test are presented in Figure 3. The amphipod (*E. estuarii*) showed a significant effect relative to reference sediment only for category 'B' material. Because pre-test pore water ammonia levels were quite high (>100 mg/L) in the category 'A' and 'B' sediments, exchanges of overlying water were performed in

accordance with the Tier III test method to reduce ammonia levels to acceptable levels prior to the addition of the test organisms. Exchanges continued for the duration of the test to ensure ammonia levels remained below the recommended threshold (30 mg/L pore water). Tests with the polychaete (*N. arenaceodonta*) showed no significant effects from exposure to any of the sediments evaluated.



* Line indicates toxicity threshold in the Amphipod (20% < reference survival) and Polychaete (10% < reference survival)

Figure 3. Results of the solid phase test for the amphipod (*E. estuarius*) and the polychaete (*N. arenaceodonta*) exposed to three classes of Venetian navigation channel sediments.

DISCUSSION AND CONCLUSIONS

Based on the results of Tier III sediment toxicity tests completed to date, it appears that the category 'A' and 'C' materials collected from Venice navigation channels would be suitable for open water disposal under the current U.S. effects-based testing program. In contrast, the category 'B' material evaluated in this study showed significant toxicity in the solid phase tests with the amphipod *E. estuarius*, exceeding the permissible concentration limit for open water disposal (*i.e.*, the results were

significantly different from reference and more than 20% less than reference for amphipods). Consequently, the category 'B' material evaluated in this study would not be suitable for open water disposal under the U.S. effects-based testing program.

Toxicity was observed in the suspended particulate phase tests for both category 'A' and 'B' materials; however, the toxicity appears to have been due to elevated concentrations of ammonia, which is not considered a contaminant of concern in dredged material evaluations. Although specified in Tier III testing protocols, the STFATE model was not applied to evaluate the suspended particulate phase test results because of the confounding effect of ammonia on the results. Furthermore, the STFATE model is not designed to evaluate disposal site conditions such as those in the Venice Lagoon, where water depth is relatively shallow (less than 1 m deep).

The results reported in this study highlight one of the major problems underlying reliance solely on chemistry in sediment assessments and evaluations of sediment quality. It is not clear why toxicity was observed in category 'B' sediment and not in category 'C' sediment, even though the concentrations of measured contaminants were higher in the 'C' sediment. The observed toxicity could be a result of differences in bioavailability, the presence of unmeasured constituents at toxic levels, or some other environmental and/or chemistry factors. Clearly, approaches based on sediment chemistry alone do not account for the possibility of interactive chemical mixtures, the presence of unmeasured constituents, or the interplay of physical factors (*e.g.*, grain size, quantity and quality of organic carbon, etc.) and chemical contamination on biological response.

Research conducted over the past few years by Word *et al.* (2000) has led to the development of a series of questions that address the potential for confounding factors to influence the outcome of sediment toxicity tests. According to Word (2000), there are four categories of confounding factors in sediment tests: persistent sediment features such as grain size and total organic carbon; non-persistent features such as ammonia and salinity; exposure and behavioral coincidence between test organisms and the contaminants in pore water and the sediment - water interface; and factors attributable to differences among laboratories involved in

conducting and reporting the results of sediment tests. Each of these four categories can have a profound affect on test results and may be responsible, in some cases, for misguided sediment management decisions.

The results of this study suggest that the current sediment classification scheme described in Venetian dredged material management guidelines is environmentally protective within the context of the specified management framework. According to the current Venetian framework, only category 'A' material is disposed in open water without restrictions. The results of Tier III toxicity testing, which reflect an effects-based approach, indicates that category 'A' material is suitable for open water disposal. Additional work is required before reaching more definitive conclusions regarding category 'A' material, and any conclusions regarding the management of category 'B' and 'C' materials. The results of sediment bioaccumulation testing are not complete at this time, and results of this testing may indicate unacceptable bioaccumulation relative to reference exposed organisms in the selected sediments. Consequently definitive conclusions regarding disposition of 'B' and 'C' sediments cannot be made until this testing is complete. As the environmental cleanup plan for the Porto Marghera area proceeds, future work will focus on expanding scientific knowledge of the Port's impacts on the Venice Lagoon, and exploring engineering solutions for appropriate future removal, treatment, and disposal of dredged material.

ACKNOWLEDGEMENTS

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Comparative Summary of Selected Contaminated Sediment Assessment Programs in the United States

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ABSTRACT: Over the past decade, regulatory programs have been developed to evaluate the magnitude and extent of sediment contamination and manage contaminated sediments. Comparative reviews of assessment programs within and between states and/or regions are rare. Yet, this type of review is essential for management areas to further develop sediment quality assessment programs.

A review was conducted as part of a larger study to summarize tools for assessing marine sediments and to detail how marine sediments are assessed in various regulatory programs. Three state programs (California, Florida, and Washington) were selected for review and comparison. These programs were selected primarily because they use multiple and different assessment tools. Information was collected from guidance and regulatory documents and by interviews with program managers. Points reviewed include program objectives, research and development, testing, criteria, regional specificity, and degree of integration with the federal dredged material management program.

Key words: sediment assessment, management, risk assessment

INTRODUCTION

In its *National Sediment Quality Survey* (USEPA, 1997), the Environmental Protection Agency established four national goals to manage the problem of contaminated sediments:

- Prevent the volume of contaminated sediment from increasing,
- Reduce the volume of existing contaminated sediment,
- Ensure that sediment dredging and dredged material disposal are managed in an environmentally sound manner, and
- Develop scientifically sound sediment management tools for use in pollution prevention, source control, remediation, and dredged material management.

If these goals are to be met, environmentally protective and economically feasible evaluative systems must be developed to accurately identify

sediment contamination and its associated ecological and human health risks. An ongoing need exists to improve existing federal and local evaluative systems and to develop new techniques for assessing sediment contamination.

A host of biological tests and numerical standards have been formulated to examine the presence of contaminants in marine sediments, their routes of exposure to marine organisms and humans, and their potential for negative ecological and human health effects. Although a great deal of information about these assessment tools exists in the form of regulatory guidance manuals, policy documents, scientific publications, and educational reports and fact sheets, it is difficult to find a comprehensive discussion of the majority of techniques and programs used to evaluate marine sediment contamination. Work presented here is a result of a larger study, which was initiated to fill this void by providing a general overview and comparison of most of the available approaches to assessing marine sediment quality.

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METHODS OF INFORMATION COLLECTION

Objectives were to review existing sediment assessment tools, document various assessment programs and how tools are used within those programs, and compare and contrast the assessment programs. This review is not a critique or advocacy of these sediment assessment programs. Information on assessment tools and programs was collected by interviews and discussions with researchers and program representatives and by literature reviews. For detailing the assessment programs, guidance, policy, and regulatory manuals were reviewed. After compilation, program descriptions were reviewed by program representatives for accuracy and corrected as necessary. The three state sediment quality programs reviewed were California (Stephenson *et al.*, 1994; State of California: SWRCB, 1998), Florida (MacDonald, 1994) and Washington (Becker *et al.*, 1989; Washington State DEP, 1991; USACE Seattle District *et al.*, 2000).

Program-aspects that were described are:

- applications: site assessments, remediation, source reduction, dredged material management;
- sediment quality criteria: if used, derivation approach, interpretation;
- tiers: is the program tiered or non-tiered;

- tests: bioassays used, medium (*e.g.* whole sediment, porewater, sediment-water interface, extracts), endpoints (reproduction, growth, survival), other (bioaccumulation assays, field benthic surveys);
- degree of integration with the regional dredged material management program; and
- status of program implementation.

CASE STUDIES

Table 1 details the various state sediment quality programs. Various tools of sediment quality assessment are utilized across all programs, however the methods of implementation vary.

APPLICATIONS

All state programs were developed for the purposes of site-characterization to assess and monitor the extent and magnitudes of sediment contamination, to identify sites of concern for remediation, and further, in Washington, for regulation of industrial discharges and other non-dredged material point sources. Only in Washington do the sediment assessment program and dredged material management program offer similar types of tests.

Table 1. Summary descriptions of three sediment quality assessment programs in the United States. Dredged material management programs are not described here. All programs in this table are used for site assessments, and in addition, Washington state's program is used for source control from point discharges. For more information about specific aspects of the assessment program, see referenced program guidance documents (MacDonald, 1994; Stephenson *et al.*, 1994; State of California: SWRCB, 1998; Washington State DEP, 1991).

Program	Sediment Quality Criteria	Structure			Bioassay Endpoints ¹		
	Derivation	tiered	non-tiered	Testing:	Reproduction	Growth ²	Survival
California							
BPTCP (Bay Protection and Toxics Cleanup Plan)	none		✓	chemical data, toxicity bioassays, field studies	✓	✓	✓
Florida							
Department of Environmental Protection	TEL/PEL; co-occurrence	✓		1: historical data, 2: chemical data, 3: toxicity bioassays ³ , bioaccumulation tests	✓ ³	✓ ³	✓ ³
Washington							
Department of Ecology ⁴	AET; co-occurrence		✓	chemical data, toxicity bioassays, field studies	✓	✓	✓

¹ Washington state program also includes tests for reduced bacterial bioluminescence in addition to listed endpoints.

² includes: developmental abnormality, reduced growth

³ Tests are not yet standardized within the state program; recommendations are to follow ASTM (American Society of Testing and Materials) protocols (MacDonald, 1994, Volume 2 and references cited therein).

⁴ Department of Ecology, Human Health also performs human health assessments on case-by-case basis, but standardized effects levels are still in development (Kissinger, L., Washington State Department of Ecology, July 2000, personal communication).

SEDIMENT QUALITY CRITERIA

Florida and Washington state programs utilize regionally-developed sediment quality criteria (whereas California's sediment quality program does not use sediment quality criteria). Both of these sediment quality criteria sets were derived using co-occurrence methods.

In Florida, sediment quality assessment guidelines (SQAGs) were developed (MacDonald, 1994) to be used in preliminary evaluations of sediment quality and to prompt evaluation at higher tiers of the sediment assessment procedure. The SQAGs were developed from an expanded version of the National Oceanic and Atmospheric Administration's (NOAA's) bioeffects database, with specific attention paid to studies conducted in the southeastern part of the United States. The studies compiled for this database included equilibrium partitioning-based guidelines, the results from spiked-sediment bioassays, and data from field investigations of sediment toxicity and benthic community structure. Raw data from these studies were subjected to statistical co-occurrence analyses to determine relationships between chemical concentrations and various observed effects and develop SQAG's (which were comprised of the Threshold and Probable Effects Levels; TEL and PEL, respectively). The TEL was defined as the upper limit of the range of sediment contaminant concentrations in the "No Effects" data set, below which significant biological effects were not expected to occur. The PEL was defined as the lower limit of the range of sediment contaminant concentrations in the "Effects" data set, above which adverse effects were expected to occur frequently or always. Finally, based on the TEL and PEL guidelines, three ranges of contaminant concentrations were identified for each contaminant (Figure 1).

The sediment quality criteria (Becker *et al.*, 1989; Washington State DEP, 1991) used in the Washington program are based on the multiple Apparent Effects Threshold approach (AET), which is an empirical approach for establishing sediment quality criteria/guidelines (Barrick *et al.*, 1989; USEPA, 1992). These guidelines are intended to be used in conjunction with bioassays for site characterizations and to prompt higher tiers of testing in the dredged material management program. The Apparent Effects Threshold (AET) for a given

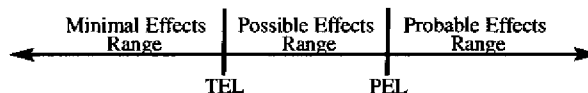


Figure 1. Diagrammatic interpretation of Threshold and Probable Effects Levels (TEL/PEL).

chemical is the concentration above which statistically significant effects are always expected (at the 95% confidence level). Chemical and biological tests were conducted on field samples from Puget Sound to identify "impacted" and "nonimpacted" sites by statistically relating observances of adverse effects (using both acute and sublethal indicators) in test sites to those in reference sites. Using only "nonimpacted" stations, the AET for a given chemical and biological indicator was the highest detected concentration (total organic carbon normalized) that was not associated with adverse effects (see Figure 2).

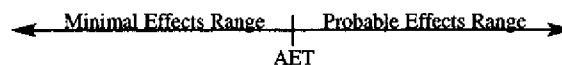


Figure 2. Diagrammatic interpretation of Apparent Effects Threshold (AET).

TIERS AND TESTS

Of the three sediment quality assessment programs reviewed, only Florida's program is tiered. California's Bay Protection and Toxics Cleanup Plan program is non-tiered. The Washington state sediment quality assessment program is tiered in the dredged material management program; yet, non-tiered for sediment quality monitoring and site characterizations for remediation.

State programs are utilizing acute and chronic toxicity tests, benthic surveys, and bioaccumulation assays within the sediment assessment programs. These tests are not always required for any given assessment (*e.g.*, dredged material management in Washington state and sediment quality assessment in Florida). Endpoints not available in the state programs, but that do exist in the research arena, include genotoxicity, intrinsic population growth, recruitment, and assays for histopathological abnormalities.

INTEGRATION WITH DREDGED MATERIAL MANAGEMENT

Federal evaluation procedures (USEPA and USACE, 1991; USEPA and USACE, 1998) for dredged material management are used in all regions, sometimes with regional-specific modifications. The Florida Department of Environmental Protection and California BPTCP are not affiliated with their respective regional dredged material management plans. However, in Washington, both federal (ACE Seattle District and EPA Region X) and state (Department of Ecology and Department of Natural Resources) agencies have jointly cooperated for the past 12 years in managing the dredged material management program (USACE *et al.*, 2000). This program uses the regionally derived sediment quality criteria in evaluating dredged materials. The standard Screening Level (SL; concentration below which adverse effects are very unlikely) and Maximum Level (ML; the concentration above which adverse effects would be expected) values used are based on the AET values that have been developed in Washington. In addition, Tier III biological tests are similar to the state's sediment quality program and are required for all sediments containing contaminant concentrations between the SL and ML values.

DISCUSSION AND CONCLUSIONS

Across just three state programs, there are major differences in sediment assessment methods and programs. Additionally, these state sediment assessment programs differ from federal dredged sediment evaluation guidance. One common purpose of all programs is to ensure that sediments are accurately characterized and meet environmental regulatory standards. Further work must evaluate and quantify the differences between the various programs' conclusions about potential for ecological and human health risks. For example, questions that must be answered include: In practice, how are these assessment programs enforced and how often does poor or incomplete implementation occur? What gaps in protection exist for each program? Is any one program's approach less sensitive for detecting potential for adverse ecological and human health risks than another? Is one program more effective and/or efficient than the other?

What are the environmental consequences of a region having different assessment program approaches (*e.g.*, for purposes of site characterization vs. dredged material management)?

Numerous techniques and tools are available for regulatory programs, including tests and approaches not currently required by the federal dredged material management program in marine waters (*e.g.*, chronic toxicity tests that measure risk to reproductive and growth endpoints in whole marine sediments). If we are to reach goals, at local and national levels, of reducing ecological and human health risks from contaminated sediments, regions must further develop and properly implement sediment assessment programs that learn from each other's progress and work together (instead of on separate tracks) towards environmentally-sound management of all sediments.

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CHAPTER 5

Policy and Management

A Decision Analysis Approach for Evaluating Capped in-Channel CAD Cells for the Boston Harbor Navigation Improvement Project

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ABSTRACT: The recently completed Boston Harbor Navigation Improvement Project relies upon capped in-channel confined aquatic disposal (CAD) cells to sequester contaminated sediments. This study uses decision analysis to evaluate the costs and environmental benefits of various suboptions that were (or could have been) considered in the decision making process. Consolidation time is related to cell depth and sediment characteristics and determines, in part, cap depth, which is a more important determiner of CAD performance than is consolidation time alone. Based on engineering costs alone, uncapped CAD cells provide more benefit per dollar allocated than do capped CAD cells. If environmental benefits are monetized, uncapped cells, by a slim margin, provide greater benefit than capped cells. If a willingness to pay is added to the benefit effectiveness assessment, then capping may be more beneficial as long as the cost does not exceed the willingness to pay amount. Furthermore, if the environmental benefit of capping is "worth it", it makes sense to remediate sediments in all portions of the harbor, and not just those involved in navigation and berthing dredging projects (approximately 33% of the total inner harbor).

Decision analysis is a useful tool in evaluating disposal alternatives, but our conclusions would be more precise if better information were available regarding: the valuation of environmental benefit, the cost structure of disposal options, and the degree to which movement of contaminated, undredged sediments undermine the benefits achieved by removal of only part of a harbor's contaminated sediment.

Keywords: CAD, capping, decision analysis, Boston Harbor, MA

INTRODUCTION

Disposal of contaminated sediments is one of the most challenging aspects of maintaining and operating navigable channels. The Boston Harbor Navigation Improvement Project (BHNIP)

constructed in-channel confined aquatic disposal (CAD) cells to sequester contaminated sediments generated during the dredging of Boston's Inner Harbor (Figure 1). Uncertainty about the stability of dredged sediments and the environmental acceptability of uncovered pits resulted in the decision to place a clean sand cap over the dredged materials (USACOE and Massachusetts Port Authority, 1995). Are such caps necessary for

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environmental protection? If pollutants continue to enter the harbor and cover clean, capped areas, is there a net environmental benefit gained from the additional project cost? This study uses decision analysis to address these issues. In addition, we address two broader questions:

- What are the costs and environmental benefits of various options for dredged material disposal?
- How useful is decision analysis as a tool to evaluate such options?

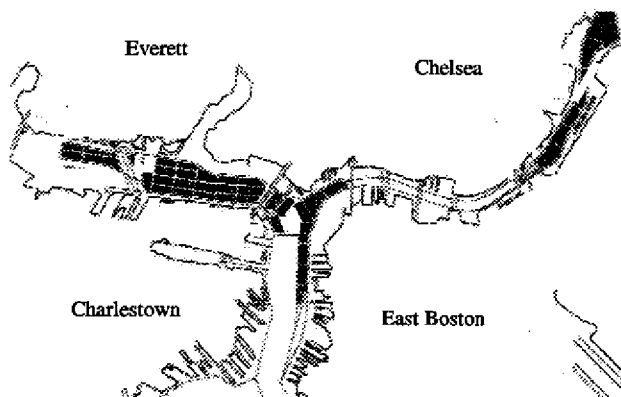


Figure 1. Map of Boston Harbor showing originally planned CAD cells (adapted from the USACOE).

APPROACH

Decision analysis provides a numerically based approach to understanding policy issues and is often employed in situations compounded by environmental uncertainty. Here, the challenge is to select numerical values for environmental components that are agreed upon by society. Our model examines costs and environmental benefits of six in-channel sediment sequestration options plus a seventh option of no environmental action (*i.e.*, simply leaving dredged sediments on the harbor floor) that is given the numerical value of zero. The six disposal options include isolation (*e.g.*, perfect sequestration within the cell, equivalent to removal of the contaminants from the site such as would occur if upland disposal were used), disposal in partially functioning shallow (5 m) and deep (15 m) cells with short (62.5 and 125 day) and long (125 and 250 day) consolidation times respectively, prior to capping (4 options) and disposal in uncapped cells.

Figure 2 shows some environmental pathways

which include: (1) loss of contaminants (sorbed to particles) during disposal events, (2) exposure of benthic organisms to contaminated sediments, (3) release of contaminants (dissolved or desorbed from sediments) into the water column, (4) resuspension of contaminants (sorbed to particles) from cells whose sediments are not well-consolidated, (5) resuspension of contaminants (sorbed to particles) from cells after an initial consolidation period, and (6) release from cells through cap (dotted because assumed to be minor). Capping reduces exposed areas, but a cap may be covered with contaminants transported from other areas including undredged harbor areas. The rate of contaminant availability as a function of time for all five environmental pathways is shown schematically in Figure 3.

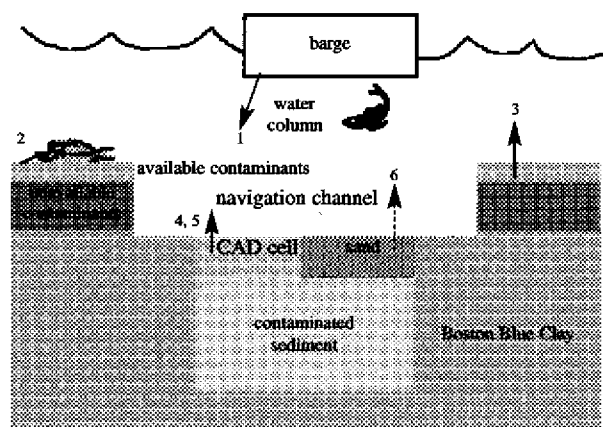


Figure 2. Environmental impacts from Confined Aquatic Disposal (CAD) cells. Arrows indicate sources of contaminants, as explained in the text. Environmental impacts reflect contaminant availability in sediments and water column.

To avoid difficulties (*i.e.* essentially a lack of data) with assigning costs to environmental benefits, an incremental benefit-cost ratio was chosen out of four possible approaches (Table 1). If all approaches were used, an incremental cost of each option with successively higher environmental benefits could be compared (de Neufville, 1990). In this study, the benefit-cost ratio was used because it is possible to use this approach without assigning monetary value to the environmental benefit. The advantage of this method is that it avoids placing a value on non-monetary benefits; the disadvantage is that it assumes there is an increasing returns to

scale, *i.e.*, there is increasing benefits with increasing costs. Using the chosen isolation option (capping), monetary values were assigned to environmental benefits for the model and sensitivity analysis was run to determine the importance of the assigned values.

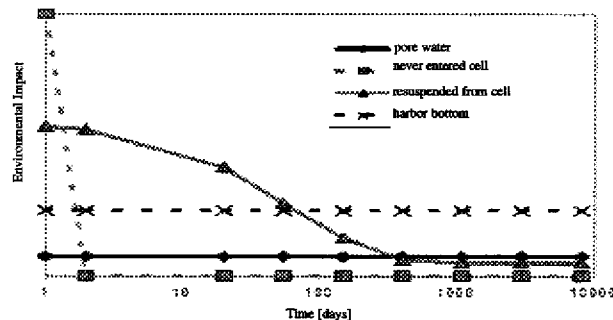


Figure 3. Qualitative representation of environmental impact versus time for five exposure pathways. "Resuspended from cell" includes both resuspension from unconsolidated sediments (non-linear portion of the curve) and resuspension from consolidated sediments (linear portion).

Table 1. This table shows four methodologies for evaluating project alternatives and the approach each takes to choosing an optimum project alternative, but only a monetized and non-monetized benefit-cost ratio was used (de Neufville, 1990).

Evaluation Methodologies	
Cost-effectiveness	Finds the maximum benefit that can be achieved for any specific cost or budget
Benefit-effectiveness	Finds the least cost of producing any level of benefit
Benefit-cost ratio	Finds the maximum of the quotient of the benefits of a project divided by its costs
Willingness to pay	Finds maximum monetary benefit given assumed monetary valuation of non-monetary benefits

RESULTS

Based on monitoring data from six cells of the BHNIP (pilot cell, Mystic River cells M4, M5, M12 and M2, plus the super cell), cap effectiveness curves were derived as a function of the cell depth and the interval of time between silt disposal and cap placement (Figure 4). Cap effectiveness reflects the degree of consolidation based on observed sediment mixing within sample cores (Sommaripa, 2000). Consolidation is shown to be positively correlated with consolidation time and

negatively correlated with silt depth. Note that one cell (M5) did not conform and was dropped from the evaluation. The cap in M5 remained intact, at a depth of approximately 1 meter.

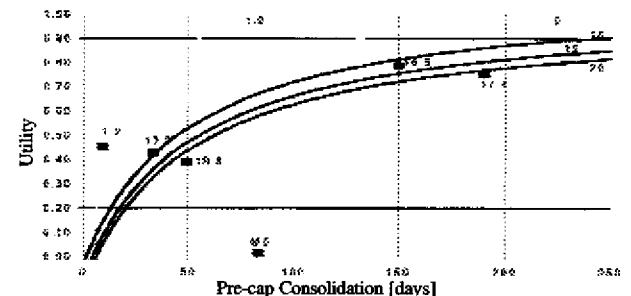


Figure 4. Cap performance curves (effectiveness of consolidation) as a function of consolidation time and cell depth (indicated parametrically) using data from BHNIP.

A monetized approach for environmental benefits (a benefit-cost ratio analysis that assumes a willingness to pay for units of environmental benefits) shows that uncapped CAD cells are the preferred alternative over capped cells and complete isolation, but only marginally (Table 2; Figure 5). However, incrementally the added benefit from the cap is low relative to the uncapped cells. Environmental benefits are highest for isolation, but costs make this option less attractive. Among capped cells, deeper cells are preferred to shallow cells and, to a lesser extent, long consolidation is preferred to shorter consolidation. Heuristically, for a given quantity of contaminated sediments to be sequestered deep cells provide more environmental benefit (from having a smaller exposed surface area) than costs (due to reduced consolidation). We note that the quantitative aspects of these conclusions reflect uncertainty with the chosen parameter values.

The value of remediating the entire harbor was also investigated (Figure 6). If only the channel is dredged, there is a significant decrease in incremental benefit-cost ratio (dotted line), whereas dredging the entire harbor shows a slight decrease in incremental return (solid line). This is based on how costs are allocated – to navigation or remediation. As the percentage of the harbor remediated increases, the effect of silt movement on reducing environmental benefits decreases because there is less contaminated silt available to cover up cleaned areas. Based on the assumptions used in this

Table 2. Base case summary results for six disposal alternatives for the base case for remediation of contaminated sediments from channel areas of the harbor. The net value is the difference between the environmental benefit and the cost of the alternative. Based on the net value, the deep cell CAD options are preferred.

Alternative	Cell Depth (m)	Consol. Interval (days)	Cost (\$x10 ⁶)	Environ. Benefit (\$x10 ⁶)	Net Value (\$x10 ⁶)
Uncapped deep CAD cells	15	n/a	11.23	41.65	30.08
Capped deep CAD cells	15	long (250)	13.20	43.59	30.03
Capped deep CAD cells	15	short (125)	13.20	43.39	29.82
Capped shallow CAD cells	5	long (125)	17.16	39.54	22.06
Capped shallow CAD cells	5	short (62.5)	17.16	38.71	21.23
Removal from site	n/a	n/a	68.08	74.04	5.34

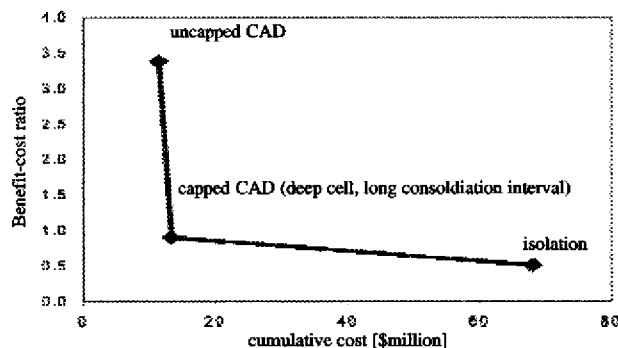


Figure 5. The three cost effective project alternatives show decreasing incremental benefit-cost ratios, (environmental benefit/\$100) which raises doubts about whether the small additional benefits of adding a cap to CAD cells justifies the relatively large incremental costs.

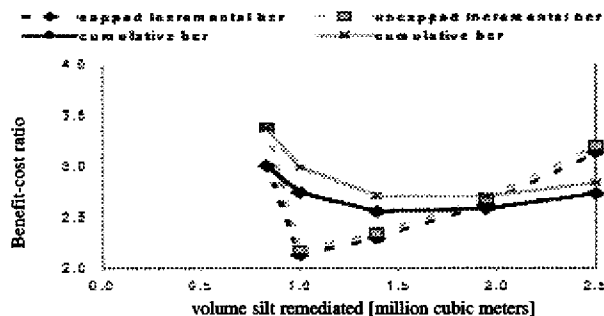


Figure 6. Both the capped (deep cell, long consolidation interval) and uncapped CAD alternatives initially show decreasing incremental benefit-cost ratios (environmental benefit/\$100) if the entire harbor is dredged. As the percentage of the non-channel areas dredged increases (data points represent remediation of 0%, 10%, 33%, 67%, and 100% of the non-channel areas of the harbor), the incremental benefit-cost ratios increase. The cumulative benefit-cost ratios are somewhat lower for dredging the entire harbor than for dredging only the channel areas of the harbor.

analysis, the willingness to pay threshold for the entire harbor is \$37/m³ of successful remediation. This is considerably lower than the incremental willingness to pay threshold for putting a cap on a CAD cell (\$112 per m³) when the option exists to use an uncapped CAD cell. Over the long-term it is worth remediating the entire harbor.

Sensitivity analysis was performed for the various alternatives and confirmed that the model is most sensitive to cost. Depending on where the willingness to pay valuation is set, a different level of remediation is recommended. Sensitivity analysis of environmental benefits show that surface area reduction and sediment movement are the most important parameters.

CONCLUSIONS

- For the valuation of environmental benefits used in Boston Harbor, uncapped CAD cells provide more benefit per dollar allocated than do capped CAD cells.
- The environmental benefit from CAD cells increases strongly as cell depth increases, and to a lesser extent as consolidation time increases.
- If the incremental cost of capped CAD cells is a worthwhile investment, then remediation of the entire contaminated harbor sediments is also worthwhile.
- The key variables that lead to uncertainty over preferred disposal alternatives are: (1) valuation of environmental benefit, (2) cost structure of disposal options, and (3) the degree to which movement of contaminated, undredged sediment undermines benefits achieved by removal of only part of a harbor's contaminated sediment.

Decision analysis is a useful tool to help policy makers understand tradeoffs among sediment disposal alternatives and how different policy and technical assumptions lead to different preferred alternatives.

ACKNOWLEDGMENTS

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The National Research Council's Environmental Dredging Windows Project: Seeking Input

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BACKGROUND

Environmental dredging windows are a management tool for reducing the environmental impacts of dredging and disposal operations on living resources, aesthetics, and recreation and tourism. Dredging windows are one of a number of management and technological tools that can be used individually or in different combinations to reduce undesirable impacts of dredging and disposal operations. The U.S. Army Corps of Engineers (ACOE) has contracted with the National Research Council's (NRC) Marine Board to conduct a study of the application of environmental dredging windows in Federal Navigation Projects. The project is being carried out in collaboration with the Ocean Studies Board.

The goals of the NRC project are to review the process by which environmental windows are set, applied, and managed, and to recommend ways to improve the process and the effectiveness of environmental windows as one of a set of management and technological tools used in managing dredging and disposal operations. The project Steering Committee sought input from the participants in the MIT Sea Grant Conference on Dredged Material Management: Options and Environmental Considerations, and a questionnaire was distributed at the conference.

The ACOE's primary interest in environmental

windows stems from the fact that currently 80% of all civil works operation and maintenance dredging projects are subject to environmental windows on a yearly basis. Environmental windows are traditionally established to protect the marine environment from the primary stressors generated during dredging operations. These stressors include:

- entrainment (juvenile and larval fishes, sea turtles and other endangered species);
- suspended sediments/turbidity/re-suspension of buried toxics and nutrients (negative impact on fish and shellfish spawning, disruption of anadromous fish migrations, reduced water quality and aesthetic degradation);
- sedimentation (burial of protected plants);
- habitat loss;
- collisions with marine mammals (*e.g.*, whales).

The establishment of environmental windows frequently involves multiple state and federal agencies many of whom may follow different procedures in recommending windows, *e.g.*, the level of justification and documentation supporting a recommended window may vary from agency to agency. The ACOE, therefore, has requested the Marine Board to examine both the scientific basis and regulatory process used to establish, manage, and monitor environmental windows.

PURPOSE

The Steering Committee plans to convene a national workshop on environmental windows on March 19 – 20, 2001 in Washington, D.C. The

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following topics will be discussed during the workshop: the statutory and regulatory basis for establishing various protection measures; the current state of the science concerning the biological/ ecological impacts of alternate dredging methodologies; new developments in dredging techniques and technologies; analytical methods for assessing costs and benefits; and, the administrative process currently followed for establishing windows in various districts.

The primary outputs from the workshop will be the following:

- An analysis of environmental dredging windows as a management tool with an emphasis on (1) their effectiveness in protecting natural resources, (2) the processes by which they are developed, applied, and managed, and (3) the other management and technological tools available that could be used in conjunction with, or instead of, environmental windows.
- A set of recommendations to improve the processes by which environmental windows are developed and to improve the efficacy of environmental dredging windows as one of a number of tools available to protect natural resources, and to promote greater consistency in their development and application across regions.

CONTACT INFORMATION

If you would like additional information regarding the Steering Committee or the Workshop, please contact either Jerry R. Schubel at (562) 951-1608 or Kris Hoellen of the Transportation Research Board at (202) 334-3385.

Evaluation of Dredging Technologies for Project Specific Needs

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ABSTRACT: The ongoing remedial design for sediment dredging and disposal at the New Bedford Harbor Superfund site will be based on prior site characterization and pilot dredging and disposal studies. From these it has been learned that selection of the dredging technology must address needs for accurate dredging, high production, and minimal resuspension and spill of sediments during dredging. Also, for successful completion of the project it is important to dredge and transport sediments minimizing water addition to the waste stream and to dredge efficiently in debris laden and shallow water depth areas.

To develop current information on the capabilities of state-of-the-art dredging equipment and verify the performance of the equipment a detailed technology evaluation was performed. New Bedford specific screening criteria were used in the technology evaluation. Two types of dredge systems were selected from the technology screening. It was decided to perform an on-site pilot dredging study of one of the dredge systems to monitor and verify dredging performance. The Pre-Design Field Test (PDFT) included monitoring of the dredging for performance parameters and environmental affects. Monitoring was conducted for dredge production, solids concentration of dredge slurry, dredging accuracy, sediment resuspension and transport (water quality), air emissions from dredging and disposal, and confirmation of clean-up goals.

Key words: contaminated sediment, pilot studies, performance parameters, environmental monitoring, New Bedford Harbor, MA

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) and U.S. Army Corps of Engineers, New England District (USACE) entered into an Interagency Agreement giving the USACE the responsibility to provide technical assistance to EPA on New Bedford Harbor, to include remedial design activities associated with the Record of Decision (ROD) for the upper and lower New

Bedford Harbor. The remedial design will be accomplished in accordance with the ROD dated September 25, 1998. The harbor sediments are contaminated with PCBs, heavy metals and other chemicals.

The remediation plan involves dredging of PCB contaminated sediments throughout the Acushnet River estuary and New Bedford Harbor and placement of dredged material in nearshore confined disposal facilities (CDFs). The cleanup will require the use of state-of-the-art dredge technology, dredging techniques, and material handling systems to be completed successfully.

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Prior dredging activities have been performed in the New Bedford Upper Harbor during the Pilot Dredging study in 1988 and 1989 (USACE, 1990), and for the Hot Spot dredging in 1995 (USEPA, 1996). While these dredging events did demonstrate the use of a number of conventional and alternative hydraulic dredging systems, the USACE requested Foster Wheeler Environmental Corporation to research more innovative technologies in an attempt to optimize the dredging process for the full scale project, particularly with regards to dredge production, dredging accuracy, and dredged material water content.

In 1999, Foster Wheeler working with the USACE performed preliminary and detailed evaluations of current, available dredge technologies to meet the specific requirements of the full-scale remediation project. The primary requirements of the dredge equipment on the New Bedford Harbor cleanup are demonstrating accessibility for dredging of the Upper Harbor given low bridge clearances and shallow water depths; minimization of resuspension of contaminated sediments; adequate dredging production; minimization of water added during the dredging process; and dredging accuracy. Following a review of these evaluations with USACE and the EPA, it was determined that a pre-design field test (PDFT) of dredging systems with demonstrated potential to meet a series of requirements for the New Bedford cleanup take place prior to final selection of the dredge system(s) to be used on the full-scale cleanup.

DREDGE TECHNOLOGY SELECTION

The report "New Bedford Harbor Cleanup Dredge Technology Review (FWENC, 1999)," provides an assessment of potential dredging technologies that can address a set of specific challenges and criteria that have been identified in previous studies and actual dredging efforts at the site. These include the following:

- Maximize solids content and thereby reduce water volume and water treatment;
- Minimize resuspension of contaminated marine sediments while dredging;
- Dredge in shallow water depths (1 to 4 feet) and inter-tidal areas;
- Perform precision dredging to minimize over-

dredging, which would add to the volumes of material requiring disposal in Confined Disposal Facilities (CDF);

- Dredge in sediment having significant debris;
- Attain relatively high production rates; and
- Minimize or eliminate odors and polychlorinated biphenyl (PCB) volatilization (control floatables and oils with specific emphasis on controlling contaminated oil releases during dredging).

Over sixty (60+) dredge technologies available in the United States and internationally were screened for application on the New Bedford Harbor project in the report. Based on the project constraints, described above, the following dredge systems and components were proposed for further investigation by Foster Wheeler. These dredge systems and components represent currently available technology that have completed full-scale environmental remediation projects and are believed to meet at least the majority of the critical New Bedford Harbor Cleanup Project parameters. These technologies were further screened and evaluated against the project criteria in a subsequent report titled *Evaluation of Dredge Technologies, Phase Two – Detailed Evaluation* (FWENC, 2000). Based on the findings of this study, the dredge technologies having the highest probability for success in meeting the New Bedford Harbor project constraints were proposed for further investigation by site demonstration or meetings with

Table 1. Screened Manufacturers of Dredge Technology.

Manufacturer / Operator	Dredge Technology
Bean Technical Excavation Corporation	Bonacavor Hydraulic Excavator
Normrock Industries	Amphibex Amphibious Excavator
Aquarius Industries	Amphibious Excavator
DRE-Technologies	Dry-Dredge
Ellicott International	Series 370HP Hydraulic Cutterhead IHC Holland
WILCO Marsh Buggies Inc.	LGP Track Mounted Excavator
Quality Industries	LGP Track Mounted Excavator
Cable Arm Inc.	Cable Arm Environmental Clamshell
Various	Land-based Earthmoving Equipment

technology representatives. These technologies included the following:

- Bean Technical Excavation Corporation (Bean TEC) *Bonacavor*,
- Normrock Industries *Amphibex*,
- Ellicott International Series 370 Hydraulic Cutterhead Dredge.

It was concluded that dredging technology used for environmental remediation dredging has changed substantially since completion of both the New Bedford Harbor Pilot Dredging Study in 1988-1989 and the Hot Spot Dredging event in 1995. Mechanical dredging techniques had been excluded for use on these two events due primarily to the inefficiency of barge transport to the disposal facility (due to shallow operating depths), concern over resuspension of contaminated sediments, and the perception that a hydraulic system creates a more uniform bottom surface.

In the 1990s, in response to a growing number of environmental remediation projects, hybrid dredging systems (the mating of a mechanical excavation system and a hydraulic transport system) have been developed and used to successfully complete a number of full-scale sediment remediation projects. The Bean Technical Excavation Corporation environmental hydraulic excavator *Bonacavor*, and the Normrock Industries *Amphibex*, are two such systems that have completed full-scale projects, and that likely would be well suited to complete portions of the full-scale cleanup at New Bedford Harbor. Conventional hydraulic cutterhead dredge systems have also been successfully used to complete contaminated sediment removal projects, including the New Bedford Harbor Hot Spot Dredging, and could successfully complete portions of the full-scale cleanup.

The Ellicott 370 hydraulic cutterhead dredge had been used during both the Pilot and Hot Spot dredging events, and, to date, had provided the best all around performance results in the site. Significant testing and data collection had been performed and documented regarding the dredge's performance. The Ellicott 370 hydraulic cutterhead dredge was therefore established as the baseline for comparison of the newer dredge technologies to be tested.

The Normrock Industries *Amphibex* was concluded to represent the most applicable type of

"amphibious" dredge technology for the full-scale cleanup in shallow and inter-tidal areas, and the manufacturer was approached to coordinate a field demonstration during the PDFT. At the time however, Normrock Industries, a Canadian firm, had manufacturing operations located only in Canada, and its dredge, having been built on a foreign hull, was precluded from operating in navigable waters of the United States, and thus subsequently deleted from participation in the PDFT. The company has since opened a manufacturing facility for the *Amphibex* in the United States, and as the hull is now not foreign built, it may be further considered for use on the New Bedford Harbor Cleanup, as well as other dredging operations in the U.S.

The PDFT therefore focused on the Bean type environmental hydraulic excavator for testing on the New Bedford Upper Harbor. Coordination between Bean Environmental LLC (BELL), and Foster Wheeler for participation in development and demonstration of a Bean type environmental hydraulic excavator suited to work within the parameters of the Upper Harbor site was initiated in early 2000.

Foster Wheeler contracted with BELL to develop a dredging system that enables selective dredging of the contaminated sediment, minimizes the amount of water added during the slurry pumping process, and recycles the dredge slurry effluent. This dredge system would be a variant of the original Bean type environmental hydraulic excavator *Bonacavor*, which was used successfully on the Bayou Bonfouca Superfund project.

BEAN ENVIRONMENTAL TEST DREDGE

BELL developed, mobilized and demonstrated a hybrid dredge (mechanical excavation/hydraulic transport), which incorporated the major innovative environmental dredging systems described below.

HORIZONTAL PROFILING GRAB (HPG)

One of the primary recommendations of the dredge technology evaluations (FWENC, 1999) and a goal of the PDFT was to apply mechanical dredging equipment to the New Bedford Harbor cleanup site. It was theorized that excavation using

a mechanical clamshell bucket could provide optimum dredging production, debris management, and dredging accuracy for the New Bedford Harbor site-specific conditions. The mechanical bucket selected for use with the BELLC dredge tested during the PDFT was the proprietary Horizontal Profiling Grab Bucket (HPG). The HPG was developed by Royal Boskalis Westminster n.v., BELLC's European partner firm, and it has been used successfully on environmental remediation projects in the Netherlands and Europe involving dredging of contaminated sediments. A 4.5 cy HPG bucket was imported to the United States for demonstration on the PDFT.

The HPG bucket is designed to excavate thin layers of material with high accuracy causing minimal spill and turbidity. The HPG bucket is operated by a hydraulic excavator, with rigid connections, as opposed to a conventional crane derrick with wire ropes. Because the HPG bucket is closed actively by hydraulic cylinders, not closing wires, its vulnerability to debris is also significantly reduced. The incorporation of a 360° horizontal hydraulically activated rotor between the excavator-stick and the HPG bucket allows the bucket to be positioned so that the cutting pattern consists of adjoining, parallel rectangles. A Caterpillar 375LC hydraulic excavator with a 27' 6" boom and an 18' 1" stick was selected as the optimal machine with which to operate the HPG bucket. The total weight of the 375LC is approximately 180,000 lbs. (Caterpillar, 1998). Modifications were made on the excavator's hydraulic system to incorporate all rotation and closure functions of the HPG at relatively low speed, to avoid turbidity during dredging. The 375LC was equipped with centimeter level accuracy Real Time Kinematic (RTK) differential global positioning system (DGPS) and the Crane Monitoring System (CMS), described in further detail below.

The HPG is designed to provide a level cut, in contrast with a conventional clamshell bucket's semi-circular or arched cut. The primary advantages of a level cut are less need for overlap between adjacent grabs to achieve grade, minimal removal of underlying (clean) material to obtain a "clean" bottom, and greater accuracy over the dredge area. The large footprint of the bucket is intended to provide optimum production in thinner layers of material with minimal addition of water.

The maximum opening of 14.75 ft., for the 4.5 cy bucket, is approximately 80% longer than that of a conventional clamshell bucket of same capacity. The HPG is also designed to be a "sealed bucket" to minimize resuspension of sediments by containing the dredged material during excavation and placement, by means of gasketed, mechanically driven seals, that close when the bucket closes.

CRANE MONITORING SYSTEM (CMS)

The proprietary CMS is an on-board electronic sensor system that provides the crane operator maximum control of the bucket while dredging, both in the horizontal and vertical planes. The CMS combines signals from the excavator boom, stick, and bucket hinges, signals from the swing of the excavator, the horizontal and vertical position of the RTK antenna, and the list, trim and orientation of the barge. These signals are assimilated in a computer that displays the entire dredge system in a graphical format, in combination with the digital pre-dredge hydrographic survey and the design dredge prism. In using the CMS, the operator dredges in pre-programmed dredge sets based on a planned horizontal and vertical grid. A heads-up display installed in the operators cab gives a record of the historical bucket position and grade achieved for every set of the dredge. The CMS display monitors were also provided in the control room and the visitor's room during the PDFT. Via telemetric link, the CMS display can also be provided to a landside office, in real time, in proximity to the dredge area.

SLURRY PROCESSING UNIT (SPU)

Minimization of the amount of water added to the dredged material is a focus area of the PDFT and the design of the full-scale remediation project. A key component of the Bean dredge *Bonacavor* that was desired to be tested for application on the New Bedford Harbor Cleanup was the patented Slurry Processing Unit (SPU) with automated control unit. The SPU system is a hydraulic slurry transport system that delivers high percent solids concentrations, by introducing controlled amounts of water to mechanically dredged material. The *in situ* material conditions dictate the theoretical

maximum achievable slurry density (*i.e.*, it is not possible to achieve solids concentrations that are higher than that of the *in situ* material).

Operation of the SPU system began after placement of the dredged material by the HPG bucket on the 6 in. x 6 in. grizzly screen of the process hopper for debris separation. To prepare the optimal mixture for the hydraulic transport, two horizontal augers were installed on the bottom of the hopper to homogenize the dredged material and to reduce the (shear-) strength of the sediment. The SPU controls system measure hopper level, suction pressure and mixture velocity along the suction line. Suction pressure and/or velocity readings below preset operating ranges indicate to the SPU operator the presence of higher than desired densities or suction line blockage. Sensors located on three specific gravity (S.G.) loops placed along the discharge line on board the dredge measure parameters by which the solids maximization process is steered. The third S.G. loop measures and records the final solids concentration of the slurry as it is pumped from the dredge to the PDFT confined disposal facility (Sawyer Street CDF).

RECIRCULATION SYSTEM

The SPU system is intended to minimize the amount of water to be added to the dredged material such that the dredge slurry density is optimized; however, the water that is added to the hydraulic transport system requires storage capacity and ultimately, treatment. Due to the full scale project parameters of large dredging volume, the requirement for hydraulic transport due to shallow water, and limited CDF capacity, efforts were made by Foster Wheeler, the USACE and Bean Environmental personnel to develop a system which would serve to further minimize the volume of discharge water to be managed on the full scale project. A water recirculation system was therefore included for testing in the PDFT.

The recirculation system involved the pumping of decant water from the CDF with a self priming 8-in. diesel driven pump, via an 8-in diameter 3,000 foot fused high-density polyethylene (HDPE) pipeline, back to the dredge for use as make up water, thereby creating a closed loop system. The make up water system for the SPU was drawn from either return water from the CDF or

harbor water via a sea chest. During the PDFT dredging, however, only return water from the CDF was used to supply the make up water pump installed on board the dredge. The make-up pump increased the pressure of the make up water to a maximum of 150 pounds per square inch (psi). The make up water supply, available at a charged manifold, was used by BELLC for a number of operations, including SPU water injectors, suction line debris jets, and a mini excavator (grizzly) debris jet.

DREDGE PERFORMANCE TESTS

The BELLC dredge and support systems were mobilized to the project site in late July 2000. With final assembly of the dredge system and movement into the dredge test area, the BELLC dredge underwent a series of performance tests. To provide the most realistic data for use in development of the full-scale remediation project, the PDFT would be conducted in areas and with equipment that would be reflective of the full-scale project, to the extent possible. A 100-ft. x 400-ft. dredge area, oriented east-west, located in the New Bedford Upper Harbor approximately 3,700 ft. north of the Coggeshall Street Bridge, was originally designated for the PDFT. The area, centered on relatively high levels (over 2,600 ppm) of PCB contamination, would contain roughly 4,000 cubic yards (cy), assuming a two ft. dredge cut. Dredge cut lanes were established, running north-south, each 30 ft. wide and 100 ft. long, with 2-5 feet of overlap. As the dredge area transitioned across varying depth, debris, sediment type, and contaminant zones, each cut area would provide discrete "sub-test" areas within which dredge performance monitoring could be performed. The depths within the dredge area ranged from roughly 5.0 feet Mean Lower Low Water (MLLW) to 0.0 feet MLLW. The minimum depth of cut in the dredge plan was 1 foot while the maximum depth of cut was 4 feet. Sediments dredged were hydraulically transported by the SPU system via the discharge pipeline to the Sawyer Street CDF. The maximum distance to the discharge within the CDF from the dredge site was approximately 2,800 feet. The PDFT Monitoring Team consisted of representatives from the USACE, USEPA, Foster Wheeler, BELLC, ENSR International, URS, Kevric and CR Environmental.

DREDGE PRODUCTION

Dredge production monitoring was performed over the course of dredge operations in the PDFT test area. Dredging was performed both with and without operational controls (reductions in advance speed and dredge cycle time) to obtain representative production rates over a range of conditions, including varying depths, bank thickness, and chemical and geotechnical conditions. BELLC collected production data using a number of electronic data collectors for the dredge systems, including flow meters, production meters, Crane Monitoring System (CMS), and slurry processing data. Foster Wheeler and BELLC production engineers recorded excavator cycle time, and production delay data throughout the duration of the tests. Production monitoring data were summarized daily, and used as baseline for the following days tests. All production monitoring data collected over the course of the PDFT, was assimilated, checked for quality, and screened for use in developing production ranges for the dredge that would be reflective of a full-scale operation.

The dredge production monitoring program yielded an average dredge production rate of 80 cy/hr, based on a 10-hour operating day, including delays. It is reasonable to assume that improvements in the areas of debris handling, dredge advance, and overall dredge efficiency could be made for the full-scale project that could bring the average dredge production rate to 95 cy/hr or greater once the system is optimized.

SOLIDS CONCENTRATION OF DREDGE SLURRY

Average sustained solids concentration values recorded by the SPU system over sustained dredging periods ranged from 13.3% to 16.3% solids by weight. These concentrations were achieved in dredge areas having in situ sediments with average solids concentrations of 32% to 43% solids by weight. The solids concentration values attained by the BELLC dredge were impacted by debris. Higher solids concentrations would be attainable with inclusion of a more sophisticated debris separation system on a full-scale project.

Of greater significance, however, was the successful demonstration of the dredge effluent water recirculation system. The recirculation system

essentially created a closed loop system, whereby the only water added to the dredge process was that entrained in the dredge bucket. This water addition amounts to on the order of 30% to 40% of the in situ volume. The water that was recycled back to the dredge was used as make up water for the SPU system, as jet water for debris management, or directed back to the hopper, from the discharge line, to increase the solids concentration of the dredge slurry. No water was used from the sea chest for make up water for hydraulic slurry transport.

DREDGING ACCURACY

Dredging accuracy will be key to minimizing the amount of overdredging while still attaining the target cleanup goals of the project. The test dredge equipment demonstrated that a mechanical bucket, operated from an excavator with rigid connections and a state-of-the-art monitoring and positioning system could achieve a +/- 4 inch vertical dredging accuracy based on comparison of the PDFT post-dredge survey with the target depths. An accuracy evaluation showed that 95% of the test area was dredged to within 6 inches of the target depth, and 90% of the test area was dredged to within 4 inches.

ENVIRONMENTAL MONITORING

PCB REMOVAL EFFICIENCY

The evaluation of the dredge efficiency at PCB removal included two components. The primary goal was to evaluate the dredge's ability to remove contaminated sediment to a given depth horizon relative to the dredging plan. The dredge performance was highly accurate in this regard. Comparison of the target dredge volume with the actual volume dredged yielded an overdredging value of only 16%, with vertical accuracy of +/- 4 inches relative to achieving the intended horizon. Comparison on pre- and post-dredging sediment PCB concentrations revealed that 97% of the PCB mass was removed over the dredged area.

A secondary objective of the PDFT was to evaluate this new dredging technology with regard to site-specific cleanup levels. It should be

understood that the project goal was **not** to leave a final sediment concentration of 10 ppm (as an average concentration over the upper one foot). The dredge performed quite well in this regard also. The average sediment PCB concentration (upper one foot) was reduced from 857 ppm to 29 ppm over the dredged area. This met the clean up criteria of 50 ppm for the Lower Harbor and approached the criteria of 10 ppm for the Upper Harbor.

WATER QUALITY MONITORING

Water quality monitoring was conducted to assess material resuspension characteristics at the point of dredging and downstream of the dredging operation. The water quality monitoring program yielded favorable results, demonstrating no major exceedances beyond compliance boundaries.

AMBIENT AIR SAMPLING

Air sampling was conducted during field testing of the BELLC dredge to assess ambient air PCB concentrations at the CDF and in the vicinity of the field test dredge area. Sampling results indicate that dredging activities are not likely to contribute significantly to air concentrations. Exposed sediment in the CDF, however, is a significant source of PCBs in air; additional controls may be required during full-scale dredging activities.

CONCLUSIONS

The PDFT was conducted August 10 - August 18, 2000, and yielded dredge performance and environmental monitoring results that significantly improved on the prior performance demonstrations at the Upper Harbor Site. The study results, summarized in the Final Pre-Design Field Test Dredge Technology Evaluation Report (FWENC, 2001), will provide the basis upon which the final dredging and dredged material conveyance plan can be engineered for the New Bedford Harbor Full Scale Cleanup.

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Use of Interactive Geographic Information Systems to Assist with Management Decisions

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ABSTRACT: Each year regulators, scientists, environmentalists, and citizens who affect the quality of our environment make thousands of decisions. These decisions are made on the basis of best available information that is complex and includes assumptions made on various components, which make the decisions difficult to evaluate. With this in mind, a new decision-making methodology was developed that utilizes Geographic Information Systems (GIS) as a way of displaying complicated information that incorporates expert scientific knowledge, but allows the user to weigh the importance of each data layer. This methodology was examined using the case study of locating dredged material disposal sites in Boston Harbor and tested with stakeholders and decision makers.

This new interactive GIS-based methodology has several advantages over conventional methodologies that include: a user friendly process, use of solid scientific information, visible and documented assumptions, broadly based, and immediate, repeatable, readily available results. Because it aids consensus building and fosters an interactive, adaptive management approach, this methodology has the potential to allow decisions to be reached in less time, with less cost, and with greater numbers of stakeholders, citizens and decision makers satisfied that a good and proper decision was reached.

Key words: GIS, adaptive management, site selection, Boston Harbor, MA

INTRODUCTION

Some of the most pressing challenges in environmental management derive from how decisions are made. The disposal of contaminated sediments from dredging urban ports and harbors is especially troublesome and complicated by diffuse and often contradictory federal and state regulations and by public perception. Additionally, costs of the project and environmental concerns related to dredging and disposal may heighten tensions among project proponents, regulators and the public leading to delays in projects or costly solutions to disposal that are of minimal value to the environment. Although the process varies from state

to state, most state and federal regulations have a provision for public input, both formally and informally as decisions are being made about contaminated sediments disposal. These include the weighty environmental impact reports, pages of regulations, and tables of details about options that require time and effort to fully grasp benefits and limitations. Difficulty in accessing and understanding the information, prolongs the process of decision-making before a project is permitted and dredging occurs. For example it took 15 years of assessment and environmental reports to fulfill state and federal regulations, secure funding, and receive final permits for the Boston Harbor Navigation Improvement Project (BHNIP) (USACOE 1988; USACOE and Massport 1994; 1995; USACOE 1996).

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Responses during public review highlighted several important components that frustrated stakeholders and are summarized, in part, below:

- Perceived failure to incorporate public input early in the process,
- Lack of confidence in a priori decisions that limit options (*e.g.* size of area, locations for siting disposal area),
- Lack of scientific input,
- Inadequate documentation of assumptions,
- Difficulty in integrating new information into decisions,
- Failure to reach consensus among stakeholders, and
- Inability to present materials so that they are easily assimilated and understood.

The perception that relevant information on regulations, costs, and environmental or other constraints is not presented in a logical and easily understood fashion will continue to plague large and complex projects. Often, stakeholders participate at various stages in the process and may not be aware of the reasons for reaching consensus on the preferred alternative. They request revisiting previous decisions, further delaying the process and sometimes overturning early consensus-based decisions. Ideally, the process should communicate all the relevant information to stakeholders in a form that allows them to evaluate the options and assess early decisions throughout the process.

Decision-making is essentially a political process that is based on interpretations and perceptions of the underlying science (de Neufville, 1990). The emergence of geographic information systems (GIS) provides tools to take complex information and display it in a visual context. One can add multiple data layers for comparisons and calculate attributes of individual or combinations of layers. In addition, it is possible to develop a program to allow users to evaluate the information. The interactive approach should use (a) scientific and technical information to establish the data layers and (b) an interactive component to allow users to evaluate "what if" scenarios.

Using Boston Harbor as an example, this paper describes a methodology that uses an interactive GIS to facilitate the identification of disposal sites for contaminated dredged materials. This methodology has the advantage of providing scientific and technical information (data layers) developed by experts and allowing participants to weight the importance of each data layer.

As part of the BHNIP, contaminated sediments from the inner harbor were deposited in confined aquatic disposal (CAD) cells in inner Boston Harbor. Approximately 1.1 million cubic yards (cy) of contaminated sediment were dredged from the main shipping channel and berthing areas and dumped in the CAD cells. Another 3.4 million cy of clean parent material (Boston blue clay) and 0.1 million cy of rock were deposited at an open water site offshore in Massachusetts Bay.

Based on the engineering plans, it was assumed that the CAD cells for the BHNIP would be located throughout the entire inner harbor and no future sites in this area would be available for disposal cells (Massport and USACOE 1995; USACOE, 1996). The remaining portions of the navigation channel are scheduled to be dredged within the next few years, but the environmental assessment process has not yet begun. The purpose of the interactive GIS approach was to identify and facilitate a decision on other potential disposal sites within greater Boston Harbor for the next dredging activity. It was assumed that regulations would be as strict or stricter in the future and the decision that led to CAD cells near the dredging site as the preferred alternative would drive the process. In addition, the decision-making methodology should be based on best available science and allow the stakeholders (decision-makers, regulators, environmental advocates, and public) to evaluate the information in an interactive format.

THE CONCEPTUAL FRAMEWORK

The first step in the program is to develop data layers for identifying suitability of sites for CAD cells based on environmental regulations, physical, chemical and biological characteristics and other parameters that are included in decisions and can be spatially displayed (Figure 1). As new information becomes available, data layers can be added or modified by appropriate experts. The second step is for the public, stakeholders, and decision makers to weight, combine and evaluate all of the expert information to arrive at a consensus. This allows public involvement in the decision-making process and is built on good scientific and technical interpretation of the data.

Based on the BHNIP Environmental Impact Report/Statement (USACOE and Massport, 1995),

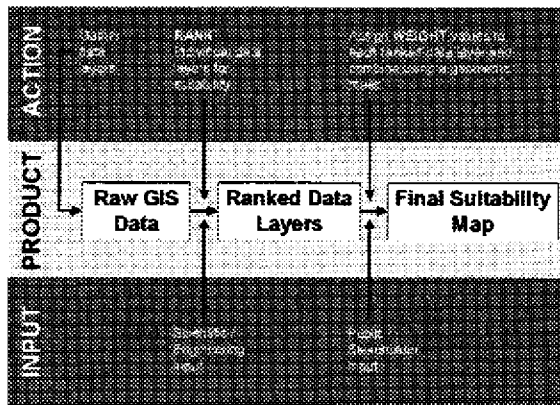


Figure 1. Flow chart depiction of how the data layers are created.

twenty-one data layers were identified for ranking by experts. However, data were available for only 13. Data were generated for bathymetry; nautical features; currents ($d=1$ mm); currents ($d=0.425$ mm); sediment type; lead contamination; coastal barrier resource units; eelgrass beds; shellfish; anadromous fish runs; lobster; recreational fishing; and swimming beaches. Data were not available for barrier beaches; depth to bedrock; benthos; endangered species; fisheries habitat; marine mammals; archeological sites; and dive sites. This approach is general enough that it would be possible to add or remove more data layers as needed. Thus, data layers on economic information or regulatory restrictions could also be added (e.g. transport cost to disposal site, no dumping areas).

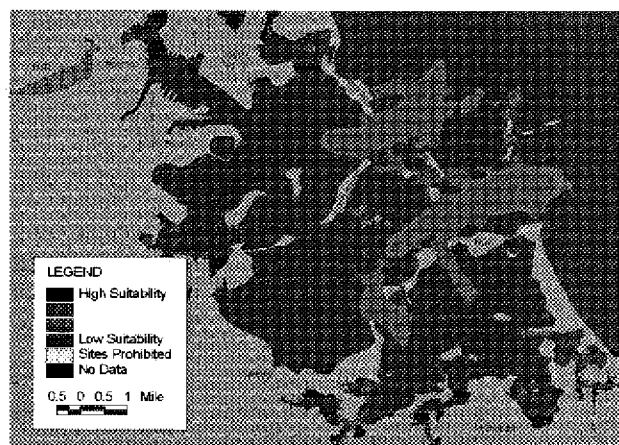
To illustrate how the process works two data layers will be examined in detail: tidal current flow and shellfish productivity. For the tidal current data layer scientists were asked to rank areas on the basis of suitability for disposal. In this case it is important that tidal current flow along the bottom is less than that required to initiate movement of capping materials, *i.e.* keeping contaminated sediments sequestered. Suitable areas are those where shear stress near the bottom will not transport sand (as capping material and assumed to have a diameter of greater than 1 mm) away from the site. Three ranking categories were chosen: (1) highly suitable were those where the ratio of bottom shear stress to the critical shear stress less than 0.8; (2) moderately suitable were areas where the ratio was between 0.8 and 0.1, and (3) least suitable were areas with the ratio greater than 0.1. The data were generated from the M2 tidal cycle in Massachusetts Bay 3-D Model (R. Signell, 1998, pers. comm. and see

<http://woodshole.er.usgs.gov/project-pages/boston-harbor/index.html>). The data were imported directly into an ArcView table and a surface grid file was created using an interpolate surface function with ArcView Spatial Analyst (ESRI, 1996).

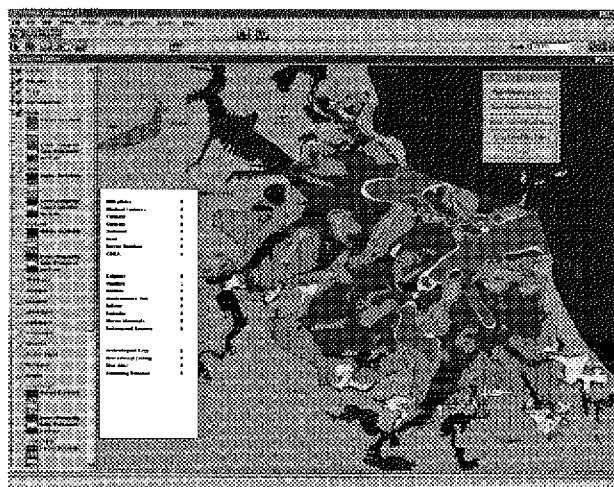
Shellfish (clams and other bivalves) are a valuable component of the harbor ecosystem and have significant commercial value. Regulations protect productive shellfish areas and prohibit alteration or destruction (T. Hoopes and D. Roach, pers. comm., DMF, 1998). The ranking scheme identified 3 general bathymetric areas (deep, mid-water, and intertidal) and two types of sediment environments (depositional and erosional). For purposes of this illustration, the following assumptions were made. All intertidal areas were considered unsuitable for disposal sites, as these are highly productive shellfish bed areas. All erosional areas are moderately (to depths of 6 ft) to highly suitable (>15 ft). Depositional areas were either unsuitable (to depths of 6 ft) or slightly suitable (>15 ft). Based on data from the Division of Marine Fisheries seven categories were created (T. Hoopes and D. Roach, pers. comm., 1998), but condensed to four categories for purposes of this illustration.

Figures 2a and b show the ranked layers for currents and shellfish, respectively, based on expert advice as discussed above. These cannot be changed unless the "experts" revise the data based on new information. Through the use of a graphical user interface (GUI) the public, stakeholders and decision-makers can weight and combine the data layers to visually inspect what emerges as "suitable sites" under different scenarios. All of the weighting controls were preprogrammed and put into simple dialog boxes using the ArcView dialog Designer extension. The user sees a slider bar for each data layer with values of 1 (low importance) to 10 (high importance). Values of zero are allowed to remove a data layer from consideration in the analysis. User input is read by an ArcView Avenue script and, with appropriate computations, a final suitability grid is generated using a weighted geometric mean.

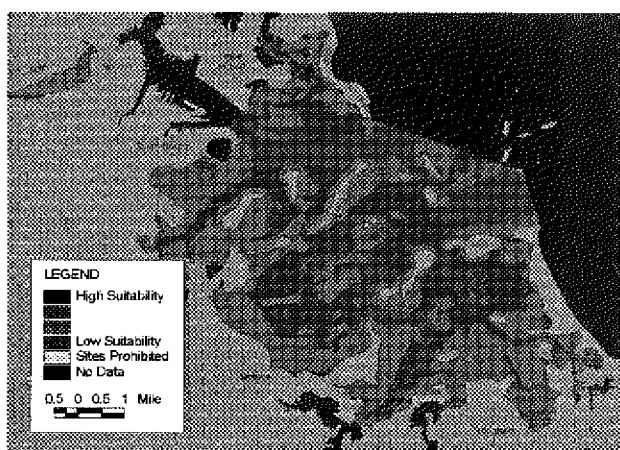
Figures 3a-c illustrates how suitable areas change under difference scenarios. If a higher weight (8 of 10) is assigned to currents and a lower weight of 3 is assigned to shellfish, the highly and moderately highly suitable areas are primarily those in the deeper basins and intertidal areas (Figure 3a). If equal weight is given to currents



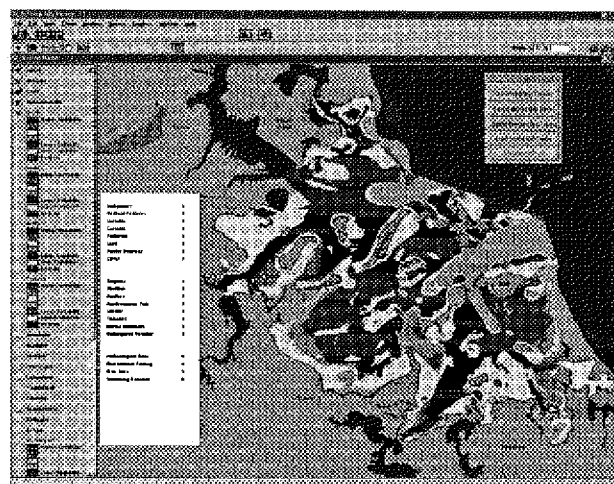
(a)



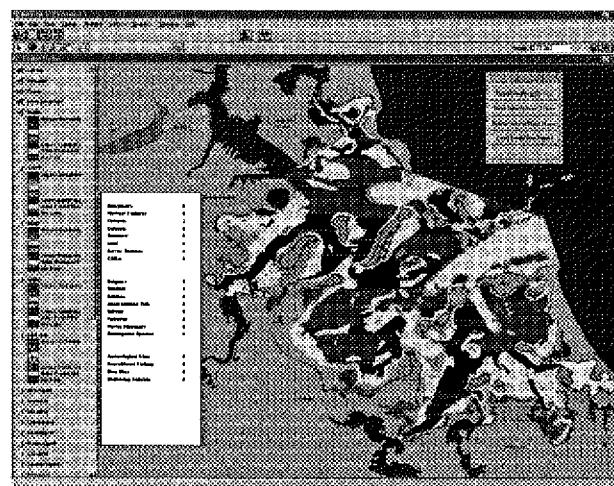
(b)



(b)



(b)



(c)

Figure 2. An example of the ranked layers for (a) currents and (b) shellfish.

and shellfish beds, then the intertidal areas are less suitable, but areas offshore are more suitable, although the picture is more complicated and reflects the importance of the complex shellfish bed layer (Figure 3b). If the weights were the reverse of the first scenario with currents assigned a weight of 3 and shellfish a value of 8, then the deeper depositional areas emerge as highly suitable and most other areas, including the main channels with highest currents are less suitable (Figure 3c). Adding additional layers generally has the effect of fragmenting the study area into smaller regions. Giving everything a high or low weighting (*e.g.* all data layers a ten or a two) will result in all data layers being equally considered. It is the relative weights that are important. It should be noted that this approach does not accommodate rate processes or data that change over time.

Figure 3. This series of figures show change in suitability under different scenarios. Darkest areas are most suitable.

As a management tool, this approach has several advantages over conventional methodologies.

- It is inherently interactive and user-friendly. The public and other stakeholders can access complicated information and manipulate it to understand the decision-making process. Many alternative "what if" scenarios can be examined in a short amount of time.
- Decisions are based on solid scientific and engineering foundations. The first step of this methodology is to evaluate information using expert scientific and engineering knowledge. How the data layers were defined and who participated in the process accompanies the ranked data, so, the decision is transparent to the user and available for all who participate at any stage of the decision-making process.
- The process includes a "universe" of information; there is no a priori discarding of sites. Neither spatial constraints (e.g. size of area) nor "not in my back yard" (NIMBY) enters into the ranking process – the data are based on biological, chemical or physical data provided by the experts.

This spatially-based approach fosters collaborative consensus building and facilitates a dialog between the various stakeholders. Decision-makers have the opportunity to examine consequences based on decisions and have a basis for responding to vague notions of what should or could happen. Unlike revisions to environmental reports that may take from several months to a year or more to respond to public input (USACOE and Massport 1994; 1995), the results are immediately available, repeatable and can be revised on the basis of new information. As spatial data become more available and computing power becomes faster and more powerful, it is possible to generate information immediately at the desktop computer. If new information is available, it can be added quickly as a new or revised data layer and analyses run again. The public becomes an active participant through the interactive component and can review outcomes with different weighting choices. Those empowered with making decisions may have access to recorded responses and use these to evaluate the public sentiment of different options. As new software is developed to make GIS more accessible to the general user, data can be made accessible through the web and responses recorded as public comments.

CONCLUSIONS

This interactive GIS methodology is a visual tool that allows the user to quickly view and understand the underlying assumptions that any decision is based upon. It aids consensus building and fosters an interactive, adaptive management approach with the potential for reaching decisions in less time, with less cost, and with greater numbers of participants. Although this example focuses on dredged material disposal siting, the approach can be used to address other complicated decisions that incorporate use of scientific and technical data in an inherently political decision making process.

ACKNOWLEDGMENTS

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Crust Management Benefits Provide Higher Placement Capacity

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ABSTRACT: Hart-Miller Island (HMI) Dredged Material Containment Facility (DMCF) is operated to contain dredged material from the Port of Baltimore and its Chesapeake Bay approach channels. The facility operates under two primary missions: to safely contain hydraulically placed dredged material ensuring quality effluent is released to the receiving waters and to use crust management practices to maximize storage volume. The island also provides numerous social benefits to the surrounding communities.

Hart-Miller Island operates on a two-season approach. Dredged material is placed on the island within the North Cell containment area, typically between October and March and active dewatering of the dredged material occurs from April through September. These seasons are commonly termed inflow and crust management, respectively.

Crust Management is that portion of operation at HMI in which the maximum effort is made to dewater and consolidate the dredged material. Numerous methods are undertaken to create drainage paths for the dewatering of the material. The management plan is broken into three parts. Phase I, soon after the sedimentation pond is dewatered, a pontoon long-reach excavator begins tracking through the cell to create drainage depressions in the freshly placed dredged material. And a perimeter drainage ditch is dug to get effluent to the spillway sumps. Phase II, once a crust is formed, low ground pressure equipment is utilized to form drainage paths for water to exit the cell. And Phase III, immediately before inflow begins again, all sumps and perimeter trenches are backfilled with dried material to facilitate easier excavation the following year. At HMI, this cycle has been utilized since 1993.

Key words: trenching, water content, sump, bench, spillway, Chesapeake Bay, MD

INTRODUCTION

The Hart-Miller Island (HMI) Dredged Material Containment Facility (DMCF) is operated to provide storage capacity for material dredged from the Port of Baltimore and its Chesapeake Bay approach channels. The facility has two primary missions: to safely contain dredged material ensuring quality effluent is released to the receiving waters and to use crust management practices to maximize storage capacity.

Hart-Miller Island operates on a two-season approach. Dredged material is placed on the island within the North Cell containment area between October and March. Active dewatering of the dredged material occurs from April through September. These seasons are commonly termed inflow and crust management, respectively.

FACILITY DESCRIPTION

The Hart-Miller Island DMCF is situated in the upper Chesapeake Bay approximately fourteen miles due east of the Baltimore Harbor. Hart-Miller

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Island was once two separate islands, Hart Island and Miller Island. These two islands, along with another island, called Pleasure Island, were part of a chain that extended in a northeasterly direction from the end of the Patapsco River Neck. Geological data indicates that these three islands were once connected to each other and to the mainland. These islands had been eroding at an ever increasing rate each year due to shoreline erosion. A dike now connects Hart Island and Miller Island.

Dike construction for the Hart-Miller Island DMCF began in September, 1981, and was completed in 1984 and lies at an elevation of +18 feet above mean low low water (MLLW). This dike was constructed with on-site sand deposits, connecting Hart Island with Miller Island. It extends nearly six miles, encloses approximately 1,140 acres, and was originally designed to hold 50 million cubic yards (mcy) of dredged material. The dike was constructed in an oval shape in order to maximize containment volume while minimizing dike volume. It was also engineered to withstand all probable physical forces imposed by the elements, while maintaining an economy of material incorporated into the dike (Hamons, 1988).

A cross-dike constructed in 1983 separates the facility into two separate sub-containment cells; the South Cell and the North Cell. The South Cell encompasses roughly 300 acres while the North Cell covers roughly 800 acres. A second tier dike was constructed adjacent to the interior of the first perimeter dike in 1988 to increase the capacity of the facility to a total of 69 mcy of internal volume. The second tier dike was constructed from +18 to +28 feet MLLW using sand dredged from the Craighill Angle and Upper Range Channels during the Port of Baltimore 50-Foot Deepening Project.

A third tier dike was added to the North Cell in 1996 raising the elevation to +44 feet MLLW and increasing its capacity by 30 million cubic yards. This dike was constructed with sand removed from the +28 ft. to +10 ft. section of the closed South Cell dike (Hamons *et al.*, 1997). Also, a perimeter bench has been constructed within the North Cell dike to facilitate equipment maneuvering during crust management. This bench is constructed of reclaimed dried dredged material and is raised seasonally to exceed the anticipated final elevation of the subsequent inflow season.

Dredged material inflow began at the Hart-Miller Island DMCF in 1984. As of June, 2000 the North Cell had received 62 mcy of dredged material and will continue to receive additional material annually until the end of the project. South Cell inflow was completed in 1990. It is filled with 16.1 mcy of material and no longer accepts dredged material.

The Hart-Miller Island DMCF is designed to accommodate the hydraulic unloading of dredged material brought to the facility in scows. In this manner, several inflow points are utilized along the cross-dike to distribute the material throughout the North Cell. The facility receives between 2.5 and 4.0 million cubic yards annually, forming a 2.0 to 5.0 ft. lift of dewatered material in the North Cell.

CRUST MANAGEMENT PLAN

Crust management plays an important role in effective utilization of placement capacity at the Hart-Miller Island Containment Facility, since the material comes to the placement cell in a slurry. The demand for maintenance dredging combined with the limited placement capacity of HMI led to the development and implementation of a crust management plan to maximize placement capacity for dredged sediments. The objective of the crust management season is to regain the maximum amount of volume occupied by water introduced by both hydraulic placement and precipitation. Post-inflow material conditions present a particularly challenging dewatering situation due to the physical properties of dredged sediments and the amount of water introduced during hydraulic placement.

Annual crust management has been practiced at HMI since 1991. Each season has had varied levels of success. The techniques presented here reflect lessons learned while applying many of the techniques developed at the U.S. Army Corps of Engineers, Charleston and Mobile Districts (U.S. Army Corps of Engineers, 1995). Some additional techniques have been tested to try new equipment or alternative crust management methods in order to better refine the plan for subsequent years.

SEDIMENT CHARACTERISTICS

The dredged sediments deposited on Hart-Miller Island come from the 100 miles of shipping channels into the Port of Baltimore that are maintained by annual dredging. These sediments are primarily fine-grained erosional deposits, classified as elastic silt with a specific gravity ranging from 2.63 to 2.67. With a unit density of 80 to 90 g/l, the slurry is approximately 20% solids by volume.

Material property analysis shows that the void ratio typically decreases by about 75% throughout the crust management season. The water content change represents a 35% to 85% decrease during crust management. Dredged material placement techniques used during the inflow season, create an unequal distribution of inflow material throughout the North Cell, limiting crust management efforts. Many variables including water content of slurry, inflow station, existing physical conditions of the north cell, pond size, discharge operations and weather conditions, all play a significant role in hydraulic placement and the distribution of inflow material throughout the North Cell. It is the goal of HMI operations to create an equal distribution of inflow over the 750 acres of the North Cell to maximize subsequent crust management efforts. This is accomplished by utilizing several key operational tools including: alternating inflow stations, alternating between or simultaneous use of spillways, and adjusting the pond size.

CRUST MANAGEMENT OPERATIONS

The crust management plan consists of three phases. During the initial phase, the site is aggressively dewatered through the establishment of spillway sumps, shallow depressions and a perimeter trench. Once the material has dried and a crust has begun to form, Phase II is implemented and the interior trenching effort is maximized throughout the entire cell. Phase II coincides with the warm, dry weather of summer to provide the best drying conditions. To properly prepare for the next inflow season, Phase III provides a transition period, which includes filling in the perimeter trench and sumps while continuing maximization of capacity by reclaiming crust material. Since activities are influenced by the timing of the inflow and the weather, all durations and start and end dates are approximate.

Phase I begins immediately following the completion of the federal maintenance dredging project inflow and lasts approximately from April 1st to May 30th. During this phase, the cell is aggressively worked to facilitate the drainage of water, utilizing a number of methods. Sumps are created at the spillways to allow solids to precipitate from the discharge waters and to allow the flow of water to access the lowest point of discharge. Sand material placed in the sumps at the conclusion of the previous crust management operations facilitate the recreation of the sumps. These sumps act as small sedimentation basins for the discharge effluent.

A perimeter trench is established around the entire cell utilizing a long-reach excavator and two conventional excavators. The perimeter trench is the primary drainage path to each of the spillways. Excavated material along the perimeter trench is side cast to dry and later spread and compacted using two low ground pressure bulldozers to widen and raise the working bench. As conditions permit, the perimeter trench is established along the perimeter bench. At the onset of crust management the material will only be able to support a small swale, but as the material solidifies, the perimeter trench area will gradually strengthen and allow deeper excavation. The trench will eventually be enlarged and migrate inward as additional passes with excavators continues. The perimeter trench is established in areas that will not compromise flow to each of the spillways. An amphibious long-reach excavator is utilized to create shallow depressions by walking in the interior of the north cell facilitating the flow of trapped water to the perimeter trench.

As a result of being able to remove surface water early in Phase I, cell conditions improve, expediting the transition into Phase II. During the early stages of the crust management season, an amphibious (pontoon) excavator is the only single piece of equipment at HMI that can effectively traverse the cell surface while leaving depressions in the slurry-like dredged material. Trenches are established at approximately 200 feet on-center at a 45-degree angle from the perimeter dike. This heringbone-pattern system continues from the cross dike down cell toward the spillway structures.

The interior trenching effort during this phase is limited due to material conditions in the cell. Almost all of the interior trenching effort during

this phase is focused in the area near the cross dike where material conditions will allow formation of trenches. A pontoon trencher is used to establish the interior trenches. This very low ground pressure tractor tows a rotary ditching device that cuts a 12 - 18 in. trench in the material. These trenches quickly fill with pore water that is carried off to the perimeter, and the side cast cuttings dry on the surface nearby.

During Phase II, the primary focus is on interior trenching, which accelerates rain water run-off and drying of the material through the removal of trapped water. The expected duration varies based on the anticipated start date of the subsequent inflow season. Generally, Phase II runs from June 1 to September 15. Some overlapping of Phase I and Phase II does occur, specifically, the perimeter trench is widened and deepened with additional passes by excavators. Areas of soft material may slough into the trench, requiring additional excavation. All sediment excavated from the perimeter trench is placed along the bench and interior slope of the perimeter dike. Once the material has sufficiently dried, it is compacted in lifts for bench building.

An amphibious long-reach excavator continues to create depression by walking across the interior of the North Cell at 45 degree angles to the perimeter dike. The wide, shallow depressions are important in Phase II for two reasons. First, the depressions draw in and expose surface water to evaporation and second, the weight of the excavator assists in compacting the material by approximately 0.5 feet.

If time permits before the subsequent Federal Maintenance Dredging inflow project begins again, interior trenches are created on a herringbone pattern within the cell. After allowing a thin crust to develop over the surface of the cell, interior trenching can begin. The amphibious trencher will begin trenching as conditions allow near the cross dike, then work to the north. The primary purpose of these interior trenches is to allow rainwater drainage and to accelerate the drying process. Trenches are established 200 feet on-center at a 45-degree angle from the perimeter dike. This system parallels the depressions previously created by the amphibious excavator. If the trenching system cannot be executed in certain areas, then trenches are established at shorter intervals in areas that can

support trenches. Areas with trapped surface water will be trenched first in order to drain water off the surface and enhance the drying process. A second aluminum pontoon trencher has been procured to perform trenching as more of the cell material has the ability to hold a trench. Favorable weather conditions towards the end of Phase II will allow trenches to be established up to every 50 feet to accelerate drying and desiccation of the dredged material.

During the dry summer months an amphibious long-reach excavator, long reach excavator, and low ground pressure bulldozers are utilized to scrape crust material along the perimeter of the North Cell to reconfigure and enlarge the operating bench. In recent seasons, up to 250,000 cubic yards of material has been winrowed, moved to the bench area, and either spread for bench building or used for trench backfilling in Phase III. This scraping has a secondary benefit in that it allows atmospheric drying to penetrate deeper into the dredged material within the cell. All of the various crust management techniques regularly implemented at the Hart-Miller Island DMCF are shown in the Applied Crust Management Techniques.

Some experimental methods have also been attempted recently to expedite drying and consolidation of the dredged material to increase volume.

- Sourgum and barley were planted at various areas throughout the North Cell dredged material. This was initiated to improve evapotranspiration by vegetative uptake (Mieghem *et al.*, 1997). Although no significant decrease in elevation was detected by survey methods, the barley planted later in the season grew very well.
- A sheepsfoot roller was utilized to compact those areas of the cell where crust scraping had exposed and somewhat loosened underlayers. The system included an 8-foot wide sheepsfoot roller towed by a rubber-tired amphibious tractor. Due to rate of travel and area covered the technique proved too costly to be very efficient.

Phase III lasts 15 to 30 days immediately prior to the start of inflow operations. To take full advantage of the crust management effort, the site should be properly prepared for the next dredging season while continuing crust reclamation to maximize available interior volume. By preparing the site suitably, the time required to begin trenching

and working the material during the subsequent crust management season is reduced significantly.

The perimeter trench is filled in to an elevation that is even with the interior of the cell. Material scraped from the inside of the cell is used to partially fill in the perimeter trench, which will remain until the end of this phase to allow rain water run-off. A low ground pressure dozer that is capable of moving onto the crust of the cell and scraping off the material and the amphibious long-reach excavator may be used to fill in the perimeter trench. The perimeter bench that was built up during Phase II is graded and used for the next years crust management season.

Interior trenching efforts will continue as long as a gain to dewatering and consolidation are achieved. With only 2 to 3 weeks left before inflow, typically the additional trenches do not add to the consolidation of the material, although they do prove beneficial if heavy rains occur. Sumps created at the spillways in Phase I are filled in using sand material recovered from areas along the cross-dike. Sand material placed in the sumps during this phase will facilitate the re-creation of sumps the following year.

These three phases are undertaken annually with up to 12 staff and 10 pieces of equipment. There have been anomalous years where longer or shorter crust management seasons are required. An annual crust management review performed by Hart-Miller Island staff members documents the resources expended in performing the work in contrast to the elevation decrease of the cell shown through bi-monthly topographic surveys and geotechnical analyses.

SUMMARY

The high demand for placement capacity at Hart-Miller led to the development and implementation of a crust management plan to maximize placement capacity for dredged sediments. The primary goal of the crust management season is to regain the maximum amount of volume occupied by water introduced by both hydraulic placement and precipitation. The crust management season may face many obstacles and adverse conditions which may limit the annual measure of success. Some of these conditions include:

- The total lift depth of inflow placed during the inflow season,
- Uneven distribution of dredged material placed during the inflow season,
- The weather, which may be the single greatest factor to a successful program.

The crust management seasonal review confirms the importance of the following factors in achieving successful seasonal crust management.

- Implementation of an aggressive crust management plan,
- Limited inflow quantities and times,
- Use of experimental crust management techniques,
- Favorable weather conditions, and
- Extended crust management window.

The use of a formulated plan to manage the dredged material once deposited within HMI-DMCF, achieves the greatest volume reduction and maximizes the storage capacity. In this manner, the large quantities of make-up water introduced from the hydraulic unloading process along with seasonal rain events can be quickly and efficiently decanted to allow optimum drying. New and innovative techniques are continually being considered, attempted, and where practicable, implemented to improve the process. At the Hart-Miller Island DMCF, crust management operations promote the desiccation and consolidation of fine-grained dredged material in the shortest time period possible. In any given year, up to 70% of the inflow volume may be removed in effluent discharge, evaporation, and consolidation of underlying layers. Optimization of limited storage capacity at the HMI-DMCF through successful crust management efforts increases available storage capacity, consequently maximizing the Maryland Port Administration's (MPA) investment in the facility while reducing the burden on other dredged material placement sites within the Chesapeake Bay. Benefits from efficient utilization of Hart-Miller Island, Dredged Material Containment Facility extend from the MPA and the Port of Baltimore to all citizens of Maryland and patrons of the Chesapeake Bay.

ACKNOWLEDGEMENTS

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Claremont Channel Deepening: A Public Private Partnership Success Story

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ABSTRACT: The Claremont Channel Deepening project is a partnership between the State of New Jersey, the City of Jersey City, Hugo Neu Schnitzer East (HNSE), Consolidated Technologies Inc. (CTI) and Liberty National Development Corporation. The existing Claremont Channel is of insufficient depth and width to support operations safely. Although the Claremont Channel is State owned, the funds allocated for the maintenance were expended on another dredging project, the Port Jersey Project, which exceeded the budgeted amount. Hart Crowser, Inc. was instrumental in forming a public private partnership to provide funding. The project encompasses:

- major site improvements in the Hugo Neu Schnitzer East metal scrap processing facility on the Claremont Channel in Jersey City, NJ;
- the dredging of 1.25 million cubic yards from the Channel to increase the depth from the current 26 feet to 32 feet (plus 2 ft overdredge);
- the construction of a multi-project dredged material processing facility to serve NY-NJ Harbor;
- the use of an innovative mixture of dredged material with PROPAT[®], a recycled product manufactured by HNSE, for the bulk fill and grading of a new golf course at Port Liberte, a residential development adjacent to the Channel;
- the use of amended dredged material for capping and grading additional acres of the golf course;
- filling portions of an abandoned mine in Pennsylvania with amended dredged material;
- the use of dredged material to construct an intertidal habitat at the head of the channel; and
- disposal at the Newark Bay Confined Disposal Facility.

The estimated cost of this project is approximately \$52 million. Hugo Neu Schnitzer East's contribution will be \$30.5 million, or 60% of the total cost. Dredging and beneficial use have an estimated cost of approximately \$40 million or \$32 per cubic yard. It is proposed that the State of New Jersey provide the balance in a combination of funds and access to other disposal options, such as the CDF in Newark Bay.

Key words: sediment processing, CDF, capping, beneficial use, Newark Bay, NJ

BACKGROUND

The Claremont Channel is owned by the State of New Jersey. The channel is 10,000 ft long and 200 ft wide without a turning basin and averages

26 ft in depth with shoals of lesser depth. Currently, vessels must back down the channel and into the scrap-loading berth. This is a safety concern to the pilots and shippers. The limited depth also requires expensive "topping off" at a second facility.

The upgrading of the Claremont Channel for improved traffic through dredging is critical to the future financial viability of HNSE and the preservation of 125 direct jobs and over 4,000 jobs

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indirectly related to this business, such as vendor services, parts suppliers and professional services.

The trend among overseas customers is towards the use of vessels drawing between 35 and 45 feet of water. The current nominal depth of the channel is 28 ft at low water; many areas have a shallower depth due to silt. This lack of water access is not only a hindrance to HNSE, but also a real impediment to developing a multi-user facility.

Efforts to federalize the Channel have been thwarted by the contaminated nature of the sediment and closure of the Mud Dump open water disposal facility for NY Harbor to all but Class I (clean) material as a cap. In order for the project to proceed innovative measures to dispose or use the material beneficially were required. This is being accomplished through several demonstration projects funded in part by the State of New Jersey.

Further, safe access to the terminal requires a wider and deeper channel. The required dredged prism would result in an improved channel 200-300 ft wide and 34 ft deep, and add a turning basin at the midpoint. This basin is needed to improve safety by allowing ships to turn before loading, and to exit the channel moving forward. The volume of material to be dredged would be approximately 1.25 million cy. The cost of dredging is estimated at \$5 million.

State transportation funds allocated to deepen and widen the channel were expended on another dredging project, the Port Jersey Project, which exceeded the budgeted amount. Hart Crowser, Inc. was instrumental in forming a public private partnership to provide funding. The project is currently underway, with the processing facility treating sediment, which is being shipped to close abandoned mines in Pennsylvania (Hugo Neu Schnitzer Inc. 1999).

DREDGING ACTIVITIES

Dredging will occur within allowable dredging windows of June 1 to January 1 in 2000 and 2001. An environmental bucket dredge will do dredging. The dredged material will be placed in barges and unloaded and/or treated at the onshore processing facility. A key consideration will be the screening of scrap metal and other debris.

SEDIMENT PROCESSING FACILITY

Consolidated Technologies, Inc. (CTI), a subsidiary of US Plastic Lumber, has completed construction and startup testing of a 4,000 cy per day facility to process dredged material from the Harbor. The facility is currently processing material from Reaches C and D of the Port Newark Channel in Newark Bay. This project has a high priority in the harbor which serves as a major international container ship facility.

The CTI processing facility is designed to be flexible enough to address sediment types and contaminant levels from multiple dredging sites and process material for different upland beneficial uses including capping brownfields and abandoned mines. The facility consists of the following components.

- Unloading facility,
- Screening / receiving hopper,
- Automated weighing conveyor belt,
- Side stream conveyor for PROPAT® or other soil like additives,
- Additive hoppers and pugmill,
- Stack loader,
- Automated control center.

The process screens out metal and debris down to a 2 in size. Raking will remove most of the very large debris before manual unloading. Further, care will be taken during manual unloading of the barge to leave behind any remaining very large debris. The feed hopper and conveyor belts are automated to allow weighing of raw sediment material and calculation of appropriate amounts of additives from side conveyors and hoppers for the intended use. The facility is located adjacent to an active rail spur and the NJ Turnpike, facilitating intermodal transfer of finished materials.

DISPOSAL / BENEFICIAL USE

The dredged material will be used in several different ways.

- PROPAT® Demonstration
- Brownfield Capping
- Pennsylvania Mine Capping Demonstration
- Intertidal Habitat Creation
- Newark Bay Confined Disposal Facility

These are described in the sections that follow.

PROPAT® DEMONSTRATION

Approximately 150,000 cy of dredged material will be mixed with PROPAT® as a demonstration project. PROPAT® is a trademarked product manufactured by Hugo Neu Schnitzer East from recycled non-metallic interior materials from automobiles. PROPAT® has been approved as alternative daily landfill cover in several states and was approved in New Jersey as a cushioning material above a landfill liner in Pennsauken. Given its soil-like properties, PROPAT® will serve as an effective dehydrating agent for the dredged material, which has an *in-situ* water content of 60-70%. PROPAT®'s fiber content will also improve the strength of the admixture which will include lime kiln dust, fly ash and other pozzolanic materials.

PROPAT®'s suitability for the proposed use as an additive, its field practicality and its cost effectiveness are being demonstrated in order to obtain a long term Acceptable Use Determination from the New Jersey Department of Environmental Protection. A demonstration program funded by to the New Jersey Department of Transportation, Maritime Resources consisting of bench scale, and pilot scale tests has been completed. A full-scale demonstration of 100-150,000 cy is scheduled for 2000 (Hart Crowser, Inc. 2000a).

The physical and chemical properties of the PROPAT®/dredged material mixture have been obtained through bench-scale laboratory tests and pilot tests. Testing methods included:

- Compaction (one point proctor) (ASTM D 1557),
- Compression (ASTM D 2850),
- Permeability (ASTM D 5084),
- Specific gravity (ASTM D 854),
- Leachability (MEP EPA 1320 as modified by NJDEP and ANSI 16.1).

The bench scale testing has indicated that the material would meet the following criteria:

- Compressive strength > 2,000 pounds per square foot,
- Bulk density > 85 pounds per cubic foot,
- Non-leaching above NJDEP GWQS.

In addition, a demonstration of the conditioned material's capabilities in the field has been accomplished through a 400 cy pilot-scale demonstration, utilizing full-size processing and earth-moving

equipment. The processed material was disked, rolled and compacted using standard construction equipment. After curing, the material was tested in the lab by using plug samples collected from the test cell. Initial results indicate that the material met requirements for strength, permeability and field applicability (Hart Crowser, Inc. 2000b).

The final, full-scale demonstration has been designed and will be implemented based on the results of the pilot tests. It is envisioned that its implementation would involve the following: extracting the dredged material; processing it with PROPAT®; trucking it to Port Liberte; and placing in bulk as fill/grading material. The estimated cost of using the dredged material to cap contaminated soil areas and develop a golf course is \$18 million (\$30 per cy) for processing the dredged material, including capping and grading. Of this total cost, \$5 million would be associated with the PROPAT® demonstration.

BROWNFIELD CAPPING

The proposed use for the bulk of the dredged material (600,000 cy) will be as capping and grading material for a golf course at the nearby 100+ acre Port Liberte site, immediately to the north of Claremont Channel. The majority of the site, formerly known as US Department of Defense Supply Depot One, functioned as a petroleum storage facility. The remainder of the site consists of commercial and industrial uses and a former paint manufacturing facility to be remediated. The site is being redeveloped as a mixed residential and golf course use by Liberty National Development Corporation.

The developer's Remedial Action Work Plan requires capping contaminated soil areas with a low permeability cover to reduce infiltration. A golf course would then be built on top. The New Jersey Department of Commerce, Maritime Resources, has suggested using the dredged materials from the Claremont Channel as cover for the golf course. The dredged material would be used for two different purposes: to cap contaminated areas and as fill for grading. Both uses will require processing the material to reduce the free water content, to stabilize contaminants, and to obtain a density appropriate to the use. Some of the material

will be mixed with additives routinely used to amend dredged materials for upland placement. By adjusting the mixture, the dredged material can be made suitable for use as capping material or simply be used as fill for grading.

PENNSYLVANIA MINE CAPPING DEMONSTRATION

Consolidated Technologies, Inc. (CTI) is undertaking a 500,000 cubic yard beneficial use project to demonstrate the use of dredged material for reclamation of abandoned mines for the Commonwealth of Pennsylvania. Pennsylvania is confronted with severe environmental problems related to over 250,000 acres of unreclaimed mine lands. Acid mine drainage and fall hazards from exposed highwalls are among the many concerns.

CTI will take 150,000 cy of the material from the Claremont Channel as part of their beneficial use project at a cost of \$6.75 million or \$45 per cy. This cost should be substantially reduced in full-scale reclamation because of economy of scale and offsets from closure reimbursement funds. The sediment will be processed at the Hugo Neu site using proprietary techniques developed by CTI for creating manufactured structural fill for remediation and reclamation of abandoned strip mines. It will then be shipped to the demonstration site in western Pennsylvania via rail and placed in the mine (O'Donnell and Henningson 1999).

INTERTIDAL HABITAT CREATION

The proposed creation of an intertidal habitat will be the final step in the program. Permitting such an in-water use will take more time than the other beneficial use activities. It is proposed that 100,000 cy of the dredged material can be placed in a proposed intertidal habitat that will extend the existing shoreline at the West end of the Claremont Channel. This area is a gently sloping beach composed of silty sand and of high water marshes with spartina and phragmites flanking a storm drainage ditch. The adjacent upland is shrub growth consisting of pioneer tree species. The area is currently used by a variety of waterfowl and shorebirds.

It is reported that nearby benthic habitat is poor, due to the organic and pathogen content of periodic sanitary discharges from the 54 in Richard

Street combined sewer outfall (CSO). CSO discharges are made into very shallow water, due to the location of its invert elevation above mean low water, and also include unsightly and unsanitary floatable matter.

The proposed intertidal habitat will be filled with the dredged material to mean low water level (MLW), and will be capped with 2-3 feet of site sand, clean fill, or stabilized material. The intertidal habitat will be contained by a natural berm, preferable to a bulkhead for esthetic and habitat reasons. The berm's face will be stabilized with concrete rubble riprap, recycled from the replacement of an existing pier on the HNSE site. This artificial reef will provide cover for young fish and benthic food chain organisms.

The proposed design includes extending the Richard Street CSO to a deeper part of the channel to improve mixing, dilution and flushing of discharges. The City of Jersey City plans to construct a structure to contain floatables under a separate program. The cost of this habitat improvement is estimated at \$4.5 million, (\$30 per cy) including CSO upgrades.

NEWARK BAY CONFINED DISPOSAL FACILITY

The balance of the dredged material, 150,000 cy, will be placed in the subaqueous Newark Bay Confined Disposal Facility (NBCDF) at a cost of \$4.5 million (\$30 per cy). This 26-acre, 70 ft deep facility was built as a disposal site for dredged material from the New York/New Jersey Harbor that is not suitable for ocean disposal. The material from Claremont Channel will be part of the 1.5 million cy of harbor sediments that the facility is designed to hold.

Material from the Claremont channel will be taken to the NBCDF in scows. At the facility, the dredged material will be placed via bottom dumping or lowering a closed environmental bucket through the water. Once the NBCDF has been filled to design capacity, it will be capped with three feet of clean sand.

SUMMARY

The Claremont Channel improvement project is a successful example of how a public-private

partnership may address the increased challenges of managing contaminated navigation dredge material. Several new management techniques resulting in beneficial use are being demonstrated. The costs (\$32 per cy) are competitive with other projects requiring the upland or confined disposal of dredged material and less than previous projects in NY Harbor.

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CHAPTER 6

Tools and Techniques

Use of Phosphate to Stabilize Heavy Metals in Contaminated Sediments

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ABSTRACT: Heavy metals are a prevalent and tenacious contaminant in many sediments and dredged materials. In a laboratory scale project, three heavy metal-contaminated sediments from Providence Harbor, Rhode Island, Newtown Creek, New York, and Cocheco River, New Hampshire, were treated with 10% phosphate and lime. The source of phosphate is an apatite mineral mined in Florida. Results of the treatment were analyzed using pH-dependent leaching experiments and X-ray powder diffraction analysis. The treatment successfully reduced the solubilities of lead by 79%, cadmium by 59%, and zinc by 50%. Spectroscopic analysis indicated the presence of several apatite minerals that had incorporated heavy metals into their structures. The use of phosphate is shown to be an effective technology for reducing the solubility of heavy metals in contaminated sediments through the formation of insoluble metal phosphate minerals. The use of a reactive barrier made from phosphate minerals to inhibit heavy metal diffusion from dredged sediment disposal facilities was also explored. Metal precipitation in the reactive barrier reduced the effective diffusivity of heavy metals by over one order of magnitude.

Key words: phosphate, contaminated sediments, lead, cadmium, zinc, stabilization, leaching

INTRODUCTION

The use of phosphate to stabilize heavy metals has been in common practice for decades in the terrestrial environment. Municipal solid waste incinerators have used them to stabilize heavy metals in both their fly ash and bottom ash waste streams (Crannell *et al.* 2000; Eighmy *et al.*, 1998; Eighmy *et al.*, 1997). Phosphates have also been used to remediate heavy metals in contaminated soils and mine tailings (Ma *et al.*, 1999; Ma *et al.*, 1997; Laperche, 1997). However, the

application of phosphate stabilization to the aquatic environment is relatively new.

The mechanism through which heavy metals are stabilized is primarily by the formation of highly insoluble metal-apatite minerals. Apatite minerals follow the basic formula of $M_5(PO_4)_3X$, where M represents a divalent cation (*e.g.*, Ca, Pb, Cd, Cu, Zn) and X represents an anion (*e.g.*, Cl, F, OH). The nature of apatite minerals makes it possible to have more than one cation or anion substituted into the structure, forming solids-solutions. A simple comparison of the solubility products for chloropyromorphite ($Pb_5(PO_4)_3OH$; $-\log K_{sp} = 84.4$) to

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cerrusite (PbCO_3 ; $-\log K_{\text{sp}} = 13.13$) indicates the large reductions in heavy metal solubility that are possible (Allison 1990). Further details on this can be found in Crannell *et al.* (2000) and Eighmy *et al.* (1997).

Reactive barriers are capping materials that actively precipitate contaminants as they diffuse from contaminated sediment, rather than passively slowing the migration. The use of insoluble phosphates as a reactive barrier offers the possibility of reducing the amount of phosphate required to stabilize heavy metals in sediment. The effectiveness of a phosphate barrier depends on its ability to immobilize heavy metals from the pore solution onto the surface of the insoluble phosphate by adsorption and surface precipitation. Continuous diffusion and subsequent precipitation within the reactive barrier also fills in the pore spaces around the phosphate materials, reducing permeability, and further inhibiting diffusion.

The primary goal of this research is to aid in the transfer of a proven treatment technology from terrestrial to contaminated sediment systems. This could provide another chemical stabilization technique that may be used alone, or in conjunction with, other remediation efforts to provide a tool for safely and permanently disposing of heavy metal-contaminated sediments. The specific goals of the research are to: optimize a phosphate stabilization treatment procedure, determine the chemical mechanisms by which phosphate stabilization takes place, and explore the use of insoluble phosphates as a reactive barrier to inhibit the diffusion of heavy metals in sediment containment structures.

MATERIALS AND METHODS

Three contaminated sediments were selected for the experiments because of their high heavy metals concentrations. These were taken from the Newtown Creek, in New York City, New York, the Providence Harbor, in Providence, Rhode Island, and the Cocheco River in Dover, New Hampshire. Lead concentrations in these sediments ranged from 636 ppm in the Newtown Creek sediment to 106 ppm in the Cocheco River. Elevated metal concentrations also existed for Zn, Cu, Cr, Cu, and Ni.

Treatment optimization took place using a partial factorial design to determine optimal phosphate

source, phosphate concentration, and treatment pH. Sources for phosphate included apatite minerals from Florida and Idaho as well as 60% phosphoric acid (H_3PO_4). X-ray powder diffraction (XRPD) analysis of these materials indicated the primary phosphate mineral to be $\text{Ca}_5(\text{PO}_4)_3\text{F}$ in both of the solids. Elemental analysis of the phosphate sources was conducted using neutron activation analysis (NAA) and x-ray fluorescence (XRF); it indicated the Florida sample contained higher phosphate concentrations and lower trace contaminant concentrations and was therefore a preferable phosphate source.

The optimized treatment formulation determined from the partial factorial design consisted of a 10% phosphate addition using Florida apatite, a reaction time of 2 hours under constant mixing in a Hobart mixer at pH 6 with a liquid to solid ratio of 1 to 1. Final pH was adjusted to 8 with lime and allowed to react for at least two weeks prior to final analysis.

Multiple analytical techniques were used to understand the immobilization / stabilization mechanisms and reaction products formed during treatment. Bulk sample crystalline mineralogy was determined by x-ray powder diffraction (XRPD) and confirmed by x-ray photoelectron spectroscopy (XPS) for detection of more amorphous species. Static and magic angle spinning (MAS) nuclear magnetic resonance (NMR) spectroscopies were used to determine the types of phosphate species and minerals present in the treated sediments. Metal solubility, as affected by treatment, was assessed through three different leaching tests including total availability leaching, pH-dependent leaching, and the toxicity characterization leaching protocol (TCLP). All of the above techniques are described at length in (Crannell *et al.*, 2000; Eighmy *et al.*, 1998; Eighmy *et al.*, 1997).

A reactive barrier study was also conducted to determine the effectiveness of apatite minerals to inhibit the diffusion of heavy metals from contaminated sediments. This was conducted in two parts, at the University of New Hampshire (UNH) and Louisiana State University (LSU). Experiments conducted at UNH included a tube experiment monitoring the diffusion of lead. These samples were frozen, sectioned into wafers, acid digested, and analyzed by inductively coupled plasma (ICP)

spectroscopy to produce the diffusion profiles. Diffusion experiments were also conducted at the Center for Advanced Microstructures and Devices (CAMD) facility located near the LSU campus. Synchrotron x-ray microtomography (SXM) was used to monitor the diffusion of Cr, Cu, Pb, and Zn through both reactive and clean barriers in a non-destructive sampling technique. Calculations of apparent diffusion coefficients were made to compare the relative effectiveness of each barrier material. Further information on this procedure can be found in van der Sloot (1987).

RESULTS

The treatment effectively reduced the solubility of lead, cadmium, and zinc in Newtown creek sediment as measured by pH-dependent leaching (see Table 1). At the same time treatment increased the solubility of chromium and copper in this sediment (Table 1). Different formulations during the preliminary optimization experiments did successfully reduce the solubility of chromium and copper, which points to the possibility that different formulations are required to treat different types of metal contamination. TCLP analysis, also presented in Table 1, demonstrated a reduction in the solubility

Table 1. Reduction in heavy metal solubility due to treatment as measure by pH-dependent leaching and toxicity characterization leaching protocol (TCLP) tests.

pH-dependent leaching ¹				TCLP leaching ²			
Element	Untreated (ppm)	Treated (ppm)	Percent Reduction ³	Element	Untreated (ppm)	Treated (ppm)	Percent Reduction ³
Pb	0.017	0.003	79 %	Pb	< 0.04	< 0.04	BDL
Cd	0.2	0.071	57 %	Cd	0.11	< 0.02	> 78 %
Zn	7.4	3.1	50 %	Zn	5.9	6.7	-36 %
Cr	0.013	0.013	-20 %	Cr	0.1	0.09	-8 %
Cu	0.017	0.019	-34 %	Cu	0.04	< 0.04	BDL
				Ag	< 0.02	< 0.02	BDL
				As	< 0.2	< 0.2	BDL
				Ba	0.31	0.25	3 %
				Hg	< 0.2	< 0.15	BDL
				Se	< 0.1	< 0.1	BDL

¹ Leaching conducted at an L:S 10:1, pH=6.0, Eh = 0.0, for 24 h with deionized H₂O.

² Leaching conducted according to EPA method 1311.

³ Calculation for % reduction includes a 20% dilution factor to account for phosphate added.

of Cd and Ba. At the same time treatment slightly increased the solubility of Cr and Zn. Because of detection limits, the changes in solubility for As, Pb, Se, Hg, and Cu could not be assessed during the TCLP test.

Many heavy metal phosphate minerals were observed in the treated sediments using XRPD, and are summarized for all three contaminated sediments in Table 2. Highly insoluble lead and cadmium apatite mineral phases were observed. However, only tertiary metal phosphate phases and their accompanying solid solutions were observed for copper and zinc. This may partially explain the less effective treatment results for these elements.

Ten-day amphipod testing was conducted on both Providence Harbor and clean sediments before and after treatment (Table 3). Results of the testing indicated that the treatment had no adverse effect on amphipod survival in the clean sediments. However, the treatment did not statistically increase amphipod survival in the Providence

Table 2. X-ray powder diffraction analysis of phosphate minerals present in treated sediments.

Mineral	Formula	PDF#
Fluorapatite, syn	$\text{Ca}_5(\text{PO}_4)_3\text{F}$	15-0876
Hydroxylapatite, syn	$\text{Ca}_5(\text{PO}_4)_3(\text{OH})$	09-0432
Carbonatehydroxylapatite, syn	$\text{Ca}_{10}(\text{PO}_4)_7(\text{CO}_3)_2(\text{OH})_2$	19-0272
Cadmium Mineral	Formula	PDF#
Cadmium Phosphate Hydroxide	$\text{Cd}_3(\text{PO}_4)_2(\text{OH})$	14-0302
Cadmium Phosphate	$\text{Cd}_3(\text{PO}_4)_2$	31-0234
Copper Mineral	Formula	PDF#
Sampleite	$\text{NaCaCu}_2(\text{PO}_4)_4\text{Cl}\cdot 5\text{H}_2\text{O}$	11-0349
Potassium Copper Phosphate	KCuPO_4	33-1006
Copper Phosphate Hydrate	$\text{Cu}_3(\text{PO}_4)_2\cdot 3\text{H}_2\text{O}$	22-0548
Lead Mineral	Formula	PDF#
Lead Oxide Phosphate	$\text{Pb}_2\text{O}(\text{PO}_4)_2$	06-0403
Lead Phosphate Hydroxide	$\text{Pb}_3(\text{PO}_4)_2\text{OH}$	08-0259
Zinc Mineral	Formula	PDF#
Sodium Zinc Phosphate Hydrate	$\text{NaZnPO}_4\cdot \text{H}_2\text{O}$	12-0055
Parascholzite	$\text{CaZn}_2(\text{PO}_4)_2\cdot 2\text{H}_2\text{O}$	35-0495
Zinc Phosphate	$\text{Zn}_3(\text{PO}_4)_2$	29-1390

Table 3. Results of the 10-day amphipod leaching tests conducted on clean and contaminated sediments.

Sediment Name	Amphipods at Start	Amphipods at 10 Days	Survival (%)	Statistical Differences
Laboratory Control	160	149	93.1	A
Clean Treated Sediment	160	147	91.9	A
Clean Untreated Sediment	160	146	91.3	A
Providence Harbor Treated	160	14	8.8	B
Providence Harbor Untreated	160	12	7.5	B

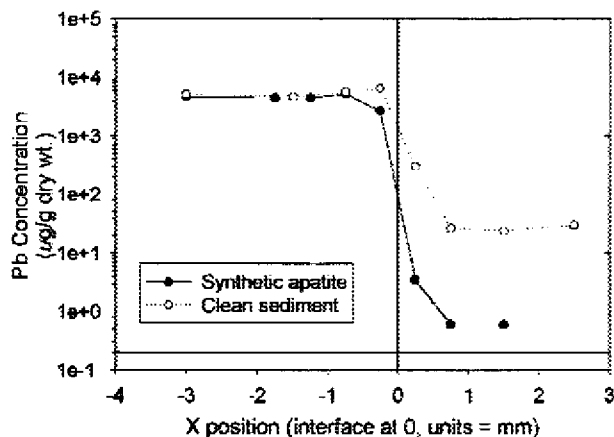


Figure 1: Diffusion of lead through reactive and non-reactive materials.

Harbor sediment. The failure to improve amphipod survival in Providence Harbor sediment is understandable, as it has multiple contaminants, including organic compounds, which would not be remediated by this technology.

Concentration profiles for the diffusion of lead through both a reactive synthetic apatite ($\text{Ca}_5(\text{PO}_4)_3\text{F}$) and non-reactive barrier (clean sediment) material are shown in Figure 1. The effective diffusion coefficient decreased from $4.5 \times 10^{-13} \text{ m}^2/\text{s}$ for a non-reactive barrier to $3.9 \times 10^{-14} \text{ m}^2/\text{s}$ for the reactive phosphate barrier. XRPD analysis of the interface between these two materials indicated the formation of hydroxypyromorphite ($\text{Pb}_5(\text{PO}_4)_3\text{OH}$), which would explain the observed reduction in lead diffusion.

CONCLUSIONS

The use of phosphates to stabilize heavy metal-contaminated sediments can be an effective and viable treatment technology. Analysis has shown that treatment effectively reduces the solubility of lead, cadmium, and zinc. Copper and chromium solubility increased due to treatment in the main treatment study. Other treatment formulations created in the preliminary studies were effective at reducing the solubility of these metals. The primary mechanism by which these observed reductions in solubility occurred is the formation of highly insoluble metal apatite minerals. Phosphates may also be an effective reactive barrier to inhibit the diffusion of heavy metals from disposal sites.

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Use of Dynamic Penetrometers to Determine Fluid Mud Properties

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ABSTRACT: During early capping operations at the Boston Harbor Confined Aquatic Disposal Project, layers of fluidized mud and suspended sediments were found on the cap sand at some locations. At issue are the physical and mechanical properties of these sediments as well as the thickness of the individual mud layers. These data are needed to assist in determining how much, if any, disposal material is transported into the water column due to the passage of ships.

A technology that shows potential for addressing these problems is the Free Fall Cone Penetrometer (FFCP) concept. A cone penetrometer (CPT) trailing a data/recovery wire falls freely through the water column, impacts the bottom and penetrates the sediment. Variations in sediment grain size, shear strength, stress and dynamic stiffness are reflected in the deceleration history recorded by the sensor package in the FFCP. The sediment pore pressure response during the penetration of the probe into the bottom provides an independent measure of shear strength and permits sediment classification in a quantitative manner. An Optical Backscatter Sensor (OBS) provides data about the amount of sediment suspended in the water column and is useful for determining the boundaries of fluff or mud layers. Bulk sediment properties such as the void ratio, porosity, water content and density can be inferred from the results when the sediment composition is known. After the CPT has stopped, it is retrieved and deployed again.

A FFCP has been beta tested at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS. The experiments examined the response of the FFCP when dropped into sand and sediment with known physical properties. This paper describes the FFCP concept and presents some initial results from the demonstration.

Key words: CPT, cone penetrometer, sediment, capping

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INTRODUCTION

The U.S. Army Corps of Engineers (Corps) is tasked with keeping the nation's ports and waterways clear for shipping. This responsibility

requires the dredging and disposal of vast amounts of sediments. A small fraction of these sediments contains hazardous materials, and Confined Aquatic Disposal (CAD) provides a way of safely and economically disposing of them. Only a limited number of CAD projects have been completed throughout the country; thus there are still some physical and mechanical processes that are not very well understood (*e.g.* consolidation rates, sediment resuspension). A relatively new tool known as the dynamic or "Free-Fall" Cone Penetrometer Test (FFCPT) has the potential to help understand these processes. Essentially, a large cone penetrometer is allowed to fall through the water column into the underlying sediment. The basis for the FFCPT is that the rate of deceleration of the penetrometer and the dynamic pore pressure response of the sediment around the penetrometer can be used to calculate the undrained shear strength (σ_u) in fine-grained sediment. A process of acceleration double integration and inversion in the time domain is used to create profiles of σ_u as well as other geotechnical properties, as a function of depth. In September 2000, Mr. Harold Christian of Christian Situ Geosciences brought a prototype free fall cone penetrometer (FFCP) from Brooke Ocean Technology, Ltd. for a series of demonstration tests at the Corps' Coastal and Hydraulics Laboratory (CHL) in Vicksburg, MS. This paper presents some initial results from those tests, and discusses them in the context of monitoring CAD projects.

EQUIPMENT AND DATA INTERPRETATION METHODS

FREE FALL CONE PENETROMETER

The Free Fall Cone Penetrometer (FFCP) package consists of an onboard microprocessor-based control and sampling system, optical backscatter sensor (OBS), two accelerometers (2 g and 20 g range), cone pressure sensor and water column pressure sensor. The control system and sensors are enclosed in a steel pressure housing with a stainless steel cone tip having a 60 degree included tip angle. The penetrometer measures 85 cm in length and 11.4 cm in diameter with a nominal

weight of 20 kg underwater, though additional ballast can be added.

Deployment of the FFCPT involves attaching a recovery tether to the tail of the instrument and then allowing it to free fall to the bottom. Penetration depends on the sediment type, varying from a few centimeters in sands to 1 meter or more in soft sediments. Initial sampling and data logging are at 1 Hz until the 500 Hz sampling mode is triggered by the controller at a preset depth. High speed sampling continues until the memory is full, which takes several seconds. Current practice is to recover the FFCPT and download the data after each test, though several tests can be performed before the onboard memory is filled. Future configurations will include near real-time data collection.

In conventional CPT, testing the rate of penetration has little effect on pore pressure response in soft, normally consolidated clays and silts, which supports the results of FFCPT testing to date. Consequently, it is feasible to interpret FFCPT data in a manner similar to standard CPT methods that give reasonable estimates of undrained shear strength and sediment layering. Two independent techniques are used to obtain shear strength data, which appear to be much more reliable than any other geotechnical measurement technique used in very soft to soft sediments. The dynamic penetration resistance (Q_d) is obtained directly from the deceleration response of the FFCPT, which is controlled by the undrained shear behaviour of the sediment. The dynamic pore pressure (U_d) is a direct physical measured response of the sediment to rapid penetration, governed by its strength and stiffness behavior. Conventional CPT theory is used to relate Q_d and U_d to the undrained shear strength (s_u) using the following expression

$$\sigma_u = \frac{(Q_d - \sigma_{vo})}{N_k} = \frac{(U_d - U_o)}{N_{\Delta u}} \quad (1)$$

The total vertical stress is denoted by σ_{vo} and U_o denotes the hydrostatic pressure at the pore pressure transducer depth. N_k and $N_{\Delta u}$ are cone correlation factors σ_u from penetration resistance and pore pressure response, respectively.

Additionally, the dynamic pore pressure parameter (B_q) and the normalized dynamic penetration resistance (Q_n), obtained using

$$B_q = \frac{(U_d - U_o)}{(Q_d - \sigma'_{vo})} \text{ and } Q_n = \frac{(Q_d - \sigma'_{vo})}{\sigma'_{vo}} \quad (2)$$

(where σ'_{vo} denotes the effective vertical stress) are useful for sediment classification. Conventional CPT-based classification charts are available for evaluating the sediment Soil Behavior Type (SBT). The standard B_q versus Q_n chart (Robertson, 1990) is a good starting point for evaluating sediment grain size characteristics from FFCPT data.

SAND PIT DEMONSTRATION

Two different types of experiments were used at the CHL to demonstrate the capabilities of the FFCP. The main goal was to evaluate the response of the FFCP to sands and sediment with known compositions. The first tests took place in a sand pit filled with water that was originally used for sand bypassing experiments until the early 1990s. The FFCP was deployed from five different stations along a floating dock into water that varied from 2.5 m to 4 m in depth. The water was relatively clear except for a layer of green algae at the surface. During the deployments a core of the first 30 cm of sediment was taken, along with a water sample from the bottom.

The core was split and found to be composed of uniform sand/gravel with a thin layer of organic silt on the top surface. The sample was dried and weighed and then was washed through a 200 mesh sieve and dried again. The change in mass was negligible. The remaining sediment was again sieved. The results showed the bottom to be composed of sand and gravel with a median diameter (d_{50}) equal to 0.6 millimeters. There was a thin layer of organics over the gravel, which was thought to be on the order of a few millimeters thick. Trials with the OBS showed the water to be essentially transparent to the sensor.

SETTLING TANK DEMONSTRATION

The second set of tests took place in a 2.5 m tall rectangular settling tank. The bottom 30 cm of the tank was filled with fine washed sand ($d_{50}=0.15$ mm) and then filled with tap water. Fifty pounds of commercial grade kaolinite was slowly sprinkled into the water and allowed to settle for

four days. The resulting layer was approximately 7 cm thick and some clay was still suspended. Two FFCP drops were made into the tank, and then samples were taken at different depths and in the kaolinite layer to determine density. Mobile Bay fluid mud was added to water and allowed to settle for one day and another drop was made, again followed by sampling. The mass and volume of each sample were measured and the bulk density determined. Densities of 1000 ± 50 Kg/m³ and 1200 ± 50 Kg/m³ were found for the water and kaolinite layer, respectively. The Mobile Bay sediments did not have time to settle so there was no appreciable density gradient or sediment layer above the kaolinite. Subsequently, the results of the last test were discarded.

INITIAL RESULTS

Figure 1a shows the output from the optical backscatter sensor as a function of time for Test #5 from the sandpit. Figure 1b shows the acceleration response and velocity (from single integration of the acceleration curve) as a function of time for Test #5. These plots are representative of the results obtained from both the pond and the laboratory tank, though there are some differences since the pond contained coarse sand and gravel while the tank contained fine sand, and the fall water depths were different. $T_i=0$ seconds on the plots was defined as the time of impact of the penetrometer as shown from the spike on the acceleration curve. Generally, the time from impact to no motion lasted less than 0.1 seconds since the bottom in both experiments was very resistant to penetration. The remaining 0.1 - 0.3 seconds of sampling usually recorded the FFCP falling over. Note in Figure 1a that the OBS curve does not begin to change until approximately 0.02 seconds after impact, since the OBS sensor is located 12.5 cm above the tip. Most pond tests penetrated to a depth of approximately 15 cm, though some did not, and no significant change occurred in the OBS reading. The results of Test #5 suggest that there was a layer of suspended sediment over the sand, though interpretation is complicated due to rapid tipping of the probe after the penetration.

Figure 2 shows the dynamic penetration resistance Q_d and the dynamic pore pressure U_d as a function of depth below seabed. A total of 13

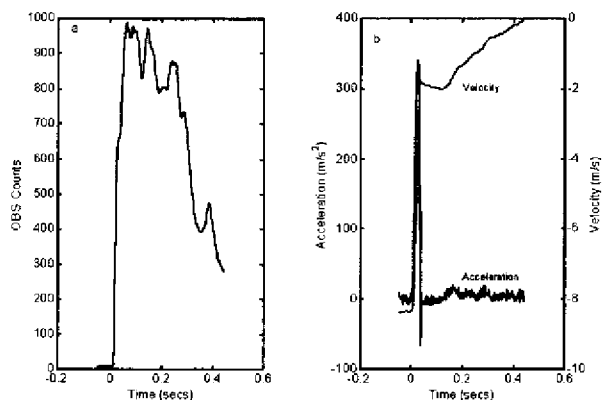


Figure 1. The OBS counts are shown as a function of time in (a). The acceleration response as a function of time is presented in (b), along with the velocity.

measurements were made during the penetration tests. Using the expressions given in Equation 2, the average normalized dynamic penetration resistance Q_n had a value of 367.3 while the dynamic pore pressure parameter B_q had an average value of -0.00789. From these values Mr. Christian predicted the sediment in the pond was gravelly sand to sand, which aptly described the $d_{50}=0.6$ mm sand/gravel pulled from the bottom. The values of Q_n and B_q from the laboratory tests described the sediment as clean sand to silty sand, similar to the 0.15 mm sand that was used. The accelerometers did not measure any change in acceleration as the probe passed through the kaolinite layer. It is possible that the clay was not dense enough to noticeably slow the probe, though another possibility is that the pressure field in front of the cone "feels" the underlying sand and masks the response of the clay layer. This point is being studied further.

CONCLUSIONS

As a result of these tests it has been determined that the Free Fall Cone Penetrometer has the potential to be a very useful tool for dredging in areas with fluid mud, and for contaminated sediment capping projects. The OBS sensor not only identifies fluid mud or suspended sediment layers, but also it can be used to measure sediment thickness as well. The accelerometers and pore pressure sensor have been shown to identify two types of sandy bottoms. The output from these sensors also

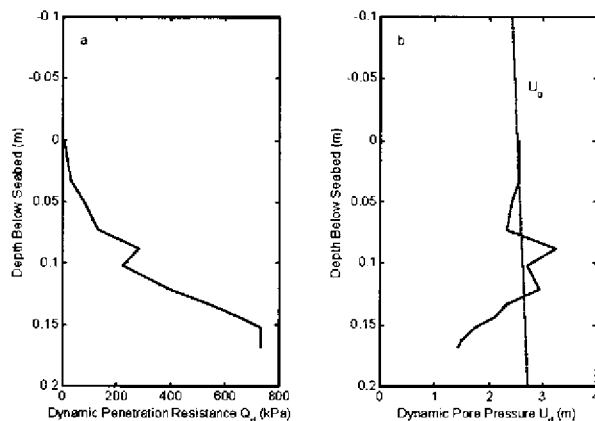


Figure 2. The dynamic penetration resistance of the sediment is given (a) while the dynamic pore pressure is given in (b).

gives the undrained shear strength of the sediment. For capping projects the ability of the FFCPT to determine the strength of the contaminated fill prior to capping is of great interest. Further investigations using the FFCPT in actual field conditions are being pursued, with the addition of more sensitive accelerometers and some type of density meter.

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Bottom Imaging for Pre-Dredge Hazard Identification on Contaminated Sediment Removal Projects

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ABSTRACT: Historically, dredging projects have focused on the removal of sediment from channel areas of navigable waterways, where anecdotal information and simple sensing instrumentation can be relied upon in the assessment of the amount and type of hazards to dredging that will be encountered. Recently, the scale of contaminated sediment cleanup projects has elevated the issue of identifying dredging hazards to a higher level. Cleanup projects such as the New Bedford Harbor Superfund Site Cleanup involve shore-to-shore dredging of large portions of entire harbors. For such projects, costly delays can occur when a complete picture of the harbor bottom is not obtained prior to the planning of the dredging.

At the New Bedford Harbor Site, Foster Wheeler Environmental Corporation scientists worked with the U.S Army Corps of Engineers to design a multi-phase imaging program focused on providing critical information in advance of the design of the dredging program. High quality images of the bottom and sub-bottom of the harbor were collected using side scan sonar, Sub-bottom Profiler, and magnetometer equipment in order to identify potential hazards to the future dredging program, and to obtain information on the character of the sediments to be dredged. In addition to locating objects of concern such as modern debris, abandoned moorings, former pilings, sunken vessels, pipelines and cables, the data revealed information concerning the relative bottom hardness. Both the hazards identification and bottom hardness information is being used in the design of the dredging program at the Harbor. The information gathered is highly useful in the determination of dredging rates and in the identification of areas of particular concern (which will require pre-dredge clearance prior to sediment removal), and has decreased the liability normally associated with large dredge design projects.

Key words: imaging technologies, seismic reflection, sub-bottom profiling, side scan sonar, magnetometry, New Bedford Harbor, MA

INTRODUCTION

The design and construction of large contaminated sediment dredging projects requires a large volume of information concerning the character of the bottom area to be dredged. Thickness of contamination, extent of contamination, sediment

type, bottom topography, and tidal and current information are all important variables that must be considered during the design and construction phases of such projects. One variable that often gets overlooked however, is the amount of debris or aberrant material that is located on or in the harbor bottom. This debris can represent a significant hazard to dredging and certain pre-design investigation activities (such as drilling or test dredge

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activities). Inadequate knowledge of the hazards to dredging can result in damage to equipment and costly delays in production if the dredging operations encounter unexpected objects or debris on or in the harbor bottom.

Assessing the presence of potential hazards to dredging and pre-design investigation activities in the marine environment is a difficult task because of the high cost of direct mapping of large underwater areas. Diving activities are costly and can be dangerous in areas where contamination is an issue. Additionally, sedimentation, sediment redistribution, and burial rates in many east coast harbors are sufficiently high as to cover over even relatively modern debris such that direct visual means of assessment may not be possible. Geophysical methods have proven very useful for situations on land, where magnetic and electromagnetic methods have been employed to determine the character of the subsurface and map out hazards prior to trenching or excavating activities. However, shallow marine conditions often interfere with geophysical signatures, particularly for electromagnetic and seismic methods, often rendering the results unusable. This paper presents the results of a program designed to overcome the issues associated with the collection of hazard information in the shallow marine environment; a program, which resulted in the collection and interpretation of critical hazard information for a large contaminated sediment dredging program.

BACKGROUND

The New Bedford Harbor Superfund Site encompasses a large portion of New Bedford Harbor and the lower reaches of the Acushnet River in southeastern Massachusetts (see Figure 1). Sediments within the harbor are contaminated with high levels of polychlorinated biphenyls (PCBs) from historic transformer manufacturing that occurred along the shoreline of the harbor. In 1998, the U.S. Environmental Protection Agency signed a Record of Decision (ROD), which prescribed a remedy for the clean-up of the harbor.

The prescribed remedy identified in the ROD calls for the dredging of the contaminated sediments from the floor of the harbor and subsequent isolation of the contaminated material in four permanent shoreline confined disposal facilities (CDFs)

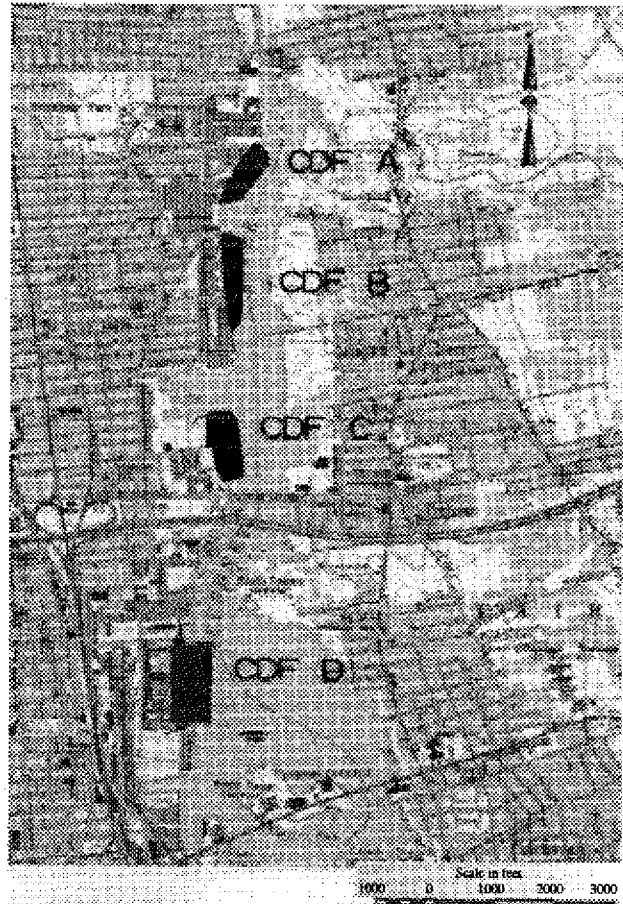


Figure 1. The New Bedford Harbor Superfund Site Plan.



Figure 2. The test dredge operating in the Upper Harbor.

constructed for this purpose. Figure 2 shows a portion of the Upper Harbor area of interest with test dredging operations observable, and a temporary CDF facility at Sawyer Street in New Bedford, which has been used for interim storage of "hot spot" and test dredge materials until the permanent CDFs can be constructed. The USEPA enlisted the

assistance of the U.S. Army Corps of Engineers - New England District (USACE) as manager of the project. Under the New England Total Environmental Restoration Contract (TERC), the USACE assigned Foster Wheeler Environmental Corp. as the lead design/build contractor for the work.

Design of a dredging program of an entire harbor requires detailed knowledge of all of the potential hazards on and in the bottom of the harbor. In the case of New Bedford Harbor, a harbor that has been developed for hundreds of years, surprises were expected. Maps of the harbor environs existed, but none were detailed, and fewer still had any information below the low water line. So in order to obtain a clear and accurate picture of the conditions in the harbor areas where future activities were planned, a multi-phase marine geophysical investigation program was designed.

METHODS

In order to acquire as much bottom and sub-bottom information as possible, a multi-phase marine geophysical program was devised. Precision imaging of the bottom of the harbor was required in order to get as complete a picture of the bottom conditions as possible. In addition, because of the concern about objects buried just below the harbor bottom, information was required from below the bottom of the harbor (from within the shallow sub-bottom sediments).

Foster Wheeler geophysicists designed a multi-phase program which integrated bottom and sub-bottom imaging technologies with the latest in positioning equipment and software. The equipment utilized for this program included:

- A precision navigation system utilizing a Differential Global Positioning System (DGPS) integrated with digital navigation software which included a steer-to heads-up display;
- A precision echo-sounder for accurate bottom depth information;
- A Cesium Total-field Magnetometer System for identification of metallic signatures on and in the harbor bottom;
- A Side Scan Sonar system (dual frequency with digital recording and playback features) for imaging of the harbor bottom; and

- A "Chirp"-type swept frequency Sub-bottom Profiler for sub-bottom imaging of the harbor bottom.

All of the equipment was housed in a shallow draft licensed survey vessel. A survey vessel capable of operating in as little as four feet of water was used for the deeper portions of the harbor. This vessel was large enough to house all of the equipment at once, allowing collection of all data streams concurrently, avoiding retracing data lines. For more shallow areas around the edges of the harbor, a second (smaller) vessel was used. This vessel required each of the instruments to be utilized independently (one at a time), as deck space was limited. With the shallow vessel configuration, work could proceed in as little as approximately one foot of water.

Prior to mobilizing the equipment to the field, survey tracklines were laid out on project maps in order to cover all areas where dredging or construction activities are scheduled or could occur. Tracklines were laid out at a 50-foot spacing such that all potentially effected areas of the harbor would be covered. The tracklines were then digitized onto the project maps, and the entire digital map image was entered into the ships navigation system. This provided the helmsman with a computerized "heads-up" display of the intended tracklines, with an overlay of the position of the vessel, updated every second, as determined from the real-time DGPS. Vessel steering was accomplished through constant monitoring of the DGPS vessel location relative to the design tracklines. During data collection, real position information was logged by the navigation computer in real time so that an accurate map of the vessels actual trackline could be produced. The data collected from each of the geophysical instruments was also logged digitally onto computer, with each piece of data tagged with digital position and time information from the DGPS.

RESULTS

The results of the survey were depicted on a series of detailed maps of the bottom of the harbor. The magnetic and side scan sonar maps were produced as composite data fusion maps of the entire harbor area surveyed for each data type. The maps

of each data type were then reviewed in detail and interpreted by experienced geophysicists, and any potential targets identified from each data type were logged and mapped on a composite interpretation map of the harbor areas surveyed. For targets displaying a data signature on more than one data type, the data signatures were noted on both the composite map and summary table of targets.

Individual images of side scan or magnetic targets were also exported from the larger composite maps so that project personnel can reference detailed images of all of the identified hazards. A library of the hazards has been generated for the project, and a summary target map, displaying all interpreted targets, has been generated for use by all project stakeholders. Many critical hazards were identified from the images, including several undocumented pipelines (see Figure 3), a set of former railway tracks, the remnants of a trestle bridge that was destroyed during a hurricane in the 1940's, several sunken (modern) vessels, and a significant volume of debris and submerged or buried old pilings. The targets are geo-referenced, and digital versions of the target map information can be downloaded into a variety of platforms (for instance the GPS system of a dredge barge), so that current and future users of the data will have access to the information and will be able to identify the potential hazards. Information will be available in digital format as well as hard copy formats.

CONCLUSIONS

Identification of potential bottom and sub-bottom hazards is an often overlooked task on contaminated sediment removal projects. Traditionally, the collection of information has been costly and not particularly reliable. However, with availability of increasingly accurate digital imaging and positioning systems has made the mapping of large harbor areas both possible and cost-effective. Such a survey was conducted for the New Bedford Harbor Superfund project, where a multi-phase marine geophysical data collection program was designed. Complete coverage of the potential dredge areas was achieved. Interpretation of the data revealed numerous surprises, including several unmapped pipelines, and a set of former railway tracks from a trestle bridge that had been

destroyed during a hurricane. Through appropriate application of technology, a significant volume of critical hazard information was collected, which can be utilized by all stakeholders on the project team. The survey of New Bedford Harbor provided engineers seeking details on the characteristics of the harbor bottom a complete picture of the harbor environs. The benefits include a significant increase in the volume of information available to engineers concerning harbor bottom character (thus improving interpretations and reducing risk), and a reduction in the cost of obtaining the information that is necessary to identify potentially costly hazards in the marine environment.

CHAPTER 7

Abstracts

Beneficial Uses of Dredged Material from Narragansett Bay

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There are currently several coastal projects where dredging is planned within Narragansett Bay, Rhode Island. These projects, which include dredging of the Providence River channel, development of a port facility at Quonset Point/Davisville, and maintenance dredging of several marinas, would generate over 10 million cubic yards (7.6 million m³) of dredged material. The issues surrounding the disposal of this very large quantity of material will have a significant impact on both economic development in the region and the environment. Current plans are to dispose of the uncontaminated sediments from the Providence River Channel either in Narragansett Bay or in Rhode Island Sound, both of which face opposition from environmental groups and local fishermen. Contaminated materials would be disposed of in a confined aquatic disposal (CAD) cell within the Providence River. With the large amount of dredged sediments being generated from the Bay, there is a clear need to consider reuse alternatives to disposal. Development of economically viable beneficial use alternatives have several attractions including reducing the need for aquatic disposal with attendant environmental advantages. Upland uses could include fill for highway construction and capping material for brownfields remediation projects. Other uses being considered are restoration of aquatic habitats and dewatering the sediments with subsequent use for beach replenishment.

This paper presents the results of a current laboratory testing program to evaluate beneficial use alternatives for uncontaminated materials from the channel and turning basins at the Quonset Point/Davisville facility. Results of a site investigation indicate that significant amounts of sand/gravel will be encountered within the planned dredged depths (approximately -42 ft MLW). The testing program includes blending sandy sediments with building debris for construction fill and compaction and hydraulic

conductivity tests of organic silts for use as capping material. The effectiveness of admixture stabilization with Portland cement, lime, and flyash is also investigated. The cost of these reuse options are compared to existing aquatic disposal options in the Bay.

Key words: Narragansett Bay, beneficial use, CAD, dredged material management

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Gravitational Flows and the Dispersion of Dredged Resuspended Sediments: The Forgotten Factor?

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Dredging in and adjacent to sensitive marine habitats often requires implementation of protocols intended to minimize the far-field dispersion of sediments resuspended by the operating dredge or discharged from the transport barge and/or the repository basin. The majority of these protocols seek to minimize resuspension through the selection of specialized equipment and the control of production rates. While significantly reducing source concentrations of suspended materials none of these methods eliminates resuspension. The resultant plume spreads under the combined effects of gravitational settling and horizontal advection. The relative importance of these two factors ultimately governs spatial settlement patterns and depositional characteristics including thickness, grain size distributions, and material composition. Horizontal advection varies as a function of local flow characteristics and is site specific. With some few exceptions, this velocity field shows minimal dependence on dredging protocols and is difficult or impossible to control. In contrast, gravitational settling rates, dependent on both the concentration and composition of the materials in suspension, display particular sensitivity to dredging protocols. Analyses of data obtained in the wake of a variety of estuarine dredging operations indicate that as source concentrations decrease settlement rates

progressively decrease and in the limit approach values governed simply by particle grain size. For fine-grained silts and clays limiting values of individual particle settling velocities can range below mm/sec resulting in long term retention of these particles in the water column and potentially significant far-field transport prior to deposition. Increasing source concentrations favors the onset of mass settling in which depositional velocities are governed by the density contrast between the plume of suspended materials and the surrounding waters. The resulting gravitational flows proceed over the vertical at rates far in excess of those characteristic of individual particle settlement. Analysis of conditions in a number of typical estuarine projects yields settling rates ranging from cm/sec to m/sec. Such rates favor minimization of far-field dispersion with settlement in large part confined to the immediate dredge site. These results suggest that efforts to minimize dredge associated resuspension may be counterproductive if the goal is to control far-field dispersion. The implications of gravitational flow analysis are discussed with the results used to develop guidelines for the specification of dredging protocols for application in both navigational and environmental dredging projects.

Key words: sediment resuspension, sediment plumes, gravitational flow, dispersion

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Assessment and Control of Sediment Contaminant Exposures: Considerations and Recommendations

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Sediment chemistry is an important component of any assessment of toxicological risk associated with bedded sediment. Both mechanistically- and correlation-based approaches have been developed to provide useful tools for assessing potential sediment toxicity based on the concentrations of chemicals or chemical classes in

bulk sediment. However, in the preponderance of cases it is not possible to account for, let alone distinguish the causes of, observed toxicity to test species based upon sediment chemistry data. We argue in this paper that our ability to make further progress in the assessment of causes of sediment toxicity will depend upon better understanding of sediment chemistry and development of methods that allow for better control of contaminant exposure in laboratory toxicity and bioaccumulation tests. Our understanding of field exposures is affected by the choice of chemical species to analyze and the experimental design used in field sampling. Laboratory toxicity and bioaccumulation experiments may not approximate *in-situ* exposure for a variety of reasons including: removal of contaminant and organic matter sources; high infaunal densities that act to deplete contaminant exposure reservoirs and oxygenate sediments; and various manipulations (including storage) of sediments or porewaters that can alter contaminant bioavailability or change the buffering capacity of contaminant in the sediments. In this paper we will provide an overview of important sediment chemistry issues that should be considered in future studies designed to assess the toxicological risks associated with in-place or dredged sediments. Questions that will be addressed include: (1) what contaminants, in addition to those conventionally measured, are most likely to be contributing to observed toxicity? (2) what are the pitfalls of field-based determinations of bioaccumulation of contaminants and what new approaches might be useful?; (3) why are pore water toxicity tests, as presently employed, inherently flawed?; (4) what are the ways in which contaminant exposures are modified in laboratory exposures with benthic invertebrates?; and (5) what general approaches might be used to best control, characterize, and mimic *in-situ* sediment exposures in the laboratory?

Key words: sediment toxicity, assessment, contaminant exposure

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Integrating Toxicology and Benthic Ecology: Putting the "Eco" Back into Ecotoxicology

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Assessing sediment toxicity can be done using benthic ecology (reality, but not predictive and difficult to discern subtle effects) and/or toxicology (least "real" in the laboratory, but can be predictive and can assess subtle effects). To date toxicology has arguably been environmental rather than ecological (ecotoxicology). Environmental toxicology tends to focus on laboratory issues and testing costs, whereas ecological toxicology focuses on ecological issues and the costs of an incorrect decision. Similarly, benthic ecology needs to be done better – the primary focus on species diversity and abundance is inappropriate; the real issue is processes. Ecotoxicology ideally provides an integration of benthic ecology and toxicology, surpassing their individual limitations. General guidelines for acute and chronic testing are provided, as are ecotoxicological criteria for species selection (contrasted with "standard" environmental toxicology criteria). Other issues discussed include: laboratory vs. field tests and mixed species testing, a detailed example of the need for ecotoxicology is presented relative to estuarine sediments. Different estuaries and their unique characteristics are reviewed (overlying and interstitial salinity as a controlling factor, bioavailability measurements, benthos – "the paradox of brackish water" and seasonal, interstitial-salinity induced movements up and down-stream). Current sediment toxicity tests, species used, end-points, problems and resolutions are also reviewed. Most testing has involved single species, but community level toxicity tests are available. These are best interpreted in combination with well-designed single species tests. Specific recommendations are provided for ensuring estuarine sediments are evaluated based on ecotoxicology, not environmental toxicology. An overall framework based on ecological risk assessment is then proposed for combining benthic ecology and toxicology to minimize uncertainty and maximize realism. Two alternatives are possible: extrinsic or intrinsic incorporation of ecology into toxicology (the latter is preferable). Final recommendations are provided which

are not solely scientific (e.g., do not separate the disciplines of ecology and toxicology; do not rely on "snapshots in time"; develop and use appropriate tools to measure ecosystem status and indications of stress). Integrating benthic ecology and toxicology in ecotoxicology represents an important shift from reductionist to holistic approaches.

Key words: sediment toxicity, ecotoxicology, assessment

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The Use of Innovative Sediment Treatment Technologies in the Great Lakes

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Beginning with the initiation of the Assessment and Remediation of Contaminated Sediments (ARCS) program in 1987, the Great Lakes National Program Office (GLNPO) has been actively involved in the development, testing, and evaluation of assessment and remediation techniques for managing contaminated sediments in the Great Lakes. As part of the 6-year ARCS program, GLNPO was responsible for the study and demonstration of appropriate treatment options for toxic contaminants in bottom sediments. At the conclusion of the ARCS program in 1994, GLNPO continued to provide financial, technical, and field sampling support for contaminated sediment issues throughout the Great Lakes. This presentation discusses results of the ARCS sediment treatment demonstration projects and the status of two innovative sediment treatment projects currently funded under GLNPO's annual grants program.

The ARCS program researched over 250 treatment technologies, most of which had not been previously demonstrated on contaminated sediments. Nine of these technologies were selected for bench-scale testing, including: solidification/stabilization, particle separation, bioremediation, base catalyzed decomposition, basic extractive sludge treatment (BEST) process, low temperature thermal desorption, wet air oxidation, thermal reduction (Ecologic process), and *in-situ* stabilization.

Based on these results, GLNPO sponsored pilot-scale demonstrations of the BEST solvent extraction and the low temperature thermal desorption processes. Reports discussing the results of bench- and pilot-scale demonstrations are available through the U.S. Environmental Protection Agency (USEPA) Great Lakes National Program Office in Chicago, Illinois. While the processed proved to be effective at removing PCBs, PAHs, and other volatile and semivolatile compounds from the sediments, cost estimates for full-scale operations indicated that these treatment would be expensive, \$250-\$535 per cubic yard of material.

With tens of millions of cubic yards of contaminated sediment within the Great Lakes basin potentially requiring remediation and/or treatment the cost of treatment could run into the billions of dollars. Additionally, space in landfills and confined disposal facilities (CDF) is running low. GLNPO and its Great Lakes partners are interested supporting the development of cost effective alternatives to landfills and CDFs. To reach this end, GLNPO is supporting feasibility scale testing of two innovative sediment treatment technologies that combine contaminated sediment treatment with the production of a marketable final product, the Glass Aggregate Feasibility Study, and the Cement-Lock pilot-scale demonstration.

The glass aggregate feasibility study uses a thermal treatment technology that is currently being used to treat paper mill sludge to produce a glass aggregate fill material. The Cement Lock process also uses a thermal treatment process to produce a blended cement product. By recovering a portion of the treatment costs through sale of the final product unit costs for each process are estimated at \$60-\$100 per cubic yard. Both demonstrations are scheduled to begin in calendar year 2001.

Key words: Great Lakes, sediment treatment technologies

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Beneficial Uses of Dredged Material: Part of the Solution to Restoration of Louisiana's Coastal Wetlands

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The U.S. Army Corps of Engineers (USACE), New Orleans District annually removes 70,000,000 to 90,000,000 cubic yards of shoal material from discontinuous reaches of 10 Federal navigational channels in coastal Louisiana. Since 1974, whenever feasible, the dredged material from routine maintenance has been used beneficially to create, restore, nourish, and protect coastal wetland habitats. Hydraulic cutterhead pipeline dredges place the dredged material into shallow, open water areas adjacent to the navigational channels in a manner conducive to wetlands development.

In the mid-1980s when the magnitude of coastal wetland loss in Louisiana became apparent, the State of Louisiana looked to the District as a partner in the effort to thwart this catastrophic land loss. The state saw the dredged material from the District's maintenance dredging program as a valuable resource to be used to create and restore coastal wetland habitats. Approximately 7000 acres of wetlands have been created and/or restored through the beneficial use of dredged material since 1985.

The State contends that a significant portion of Louisiana's coastal wetlands could be restored annually if all of the dredged material from the District's maintenance dredging program were used in a beneficial manner. However, in addition to the Corps of Engineers' policy relative to a "Federal Standard", a number of other factors limit the amount of coastal wetlands restoration that can be accomplished using dredged material from maintenance of Federal navigational channels. Among these factors are: 1) logistics; 2) chemical and physical characteristics of the dredged material; 3) channel dynamics; and 4) lands, easements, rights-of-way, relocations and disposal areas. Changes in the Corps' policy would not remove all limitations imposed by these factors; therefore, beneficial uses of dredged material from the District's maintenance dredging program will remain

only part of the solution to restoration of Louisiana's coastal wetlands.

Key words: beneficial use, wetland restoration, land loss, Louisiana, Gulf of Mexico

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Review of Comparative Risk Assessment Methods and their Applicability to Dredged Material Management Decisions

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The purpose of this paper is to review the status of comparative risk assessment within the context of environmental decision-making, to evaluate its potential application as a decision-making framework for selecting alternative technologies for dredged material management, and to make recommendations for implementing such a framework. We provide the various definitions of comparative risk assessment, review the relevant literature concerning its application, or more often, suggested application, in policy development, regulatory prioritization, technology selection, and chemical hazard comparisons. We summarize the various methods and critiques of comparative risk assessment, and suggest its potential application in helping to select among various technology options for dredged material management.

This review demonstrates that comparative risk assessment has not found a successful universally applied methodology or approach. Rather, the literature largely offers comparisons of specific chemicals based on current risk assessment approaches, descriptions of specific applications that are variations on an U.S. Environmental Protection Agency (USEPA) theme for setting policy agendas, or critiques of methodology with the hope that it may find an application.

One of the most important points from this review for the United States Army Corps of Engineers (USACE) is that comparative risk assessment, however conducted, is an inherently subjective, value-laden process. There is some objection to this lack of total scientific objectivity (referred to as the "hard version" of comparative risk assessment). However, the "hard versions" provide little help in suggesting a method that surmounts the psychology of choice in any decision making scheme. The application of comparative risk assessment in the decision making process at dredged material management facilities will have to an element of value and professional judgement in the process.

The literature suggests that the best way to incorporate this subjectivity and still maintain a defensible comparative framework is to develop a method that carefully selects the basis for comparisons and is inclusive of various perspectives. The method must be logically consistent and allow for uncertainty by comparing risks on the basis of more than one set of criteria, more than one set of categories, and more than one set of experts. It should incorporate a probabilistic approach where necessary and possible, based on management goals. The general opinion is that iteration within the comparative risk framework lends some sense of the range of outcomes to an inherently subjective analysis.

Key words: risk assessment, dredged material management, methodology

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Dredging in the New York Harbor: From Crisis to Management

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The New York/New Jersey Harbor is naturally shallow with a reported natural depth of about 18 feet. The Harbor has been dredged since the late 1800s to provide sufficient draft for vessels of increasing size. Currently, channel depths in the Port of New York and New Jersey

are as deep as -40 feet below the plane of mean low water (MLW). Additional deepening of the channels has recently begun to bring their depths to -45 MLW and studies are on going which could further increase channel depths to -50 MLW. Since dredging in the New York Harbor began, dredged material has been disposed of in the ocean about six miles off the coast of New Jersey. In the early 1990s, New Jersey's philosophy concerning dredged material management began to shift away from mere disposal of dredged material to a comprehensive management strategy centered on the beneficial use of dredged material. In 1997, the Mud Dump, which had for years been used to dispose of millions of cubic yards of dredged material from the Port of New Jersey and New York, was officially closed which left the largest port on the Eastern Seaboard with virtually no dredged material disposal alternatives. Consequently, the transition to beneficial use took on new urgency in 1997.

In response to the impending crisis, the New Jersey Department of Environmental Protection and private sector partners began an innovative program aimed at using dredged material from the New York Harbor to facilitate the closure of abandoned landfills and the remediation of brownfield sites in the metropolitan region. The primary goal of the program is to successfully manage dredged material in a manner that is protective of human health and the environment. An added benefit of the program is the remediation of contaminated upland sites in urban areas and their restoration to economic use. The first site to be successfully remediated using dredged material was the Elizabeth Landfill, now home of the Jersey Gardens Mall. This management strategy is presently being expanded to other areas of the State including the Delaware River, thereby renewing capacity at existing confined disposal facilities and eliminating the need to expand or site new facilities.

This paper will provide a brief chronicle of the emergence of New Jersey's dredged material management policy and its implementation through existing regulatory programs, and the development of New Jersey's dredging technical manual. The paper will focus on regulatory considerations for determining acceptable uses for dredged material including sampling frequency, testing protocols and choosing appropriate evaluative criteria, and will present an upland beneficial use case study of a currently active brownfield redevelopment. Lastly, the paper will discuss impediments to the success of the program and on-going research initiatives intended to address outstanding questions including the volatility of

contaminants.

Key words: dredged material disposal, beneficial use, dredging policy, New York/New Jersey Harbor

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Sediment Toxicity Prediction

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The Equilibrium Partitioning (EqP) model is the basis for our current ability to understand and predict the causes of toxicity in sediments. It also forms the framework for toxicity identification evaluations (TIEs) in sediments. The data that support the assumptions in the model will be reviewed for both organic chemicals and metals. Recent applications of EqP to predicting the toxicity of mixtures of polycyclic aromatic hydrocarbons (PAHs) in sediments using narcosis theory will be presented. An extension of the simultaneous extracted metal-acid-volatile sulfides (SEM-AVS) model to improve the prediction of toxicity of metals in sediments – in addition to its already demonstrated ability to predict the lack of toxicity – will also be discussed. Finally the limitations of the EqP model for organic chemicals and metals will be examined, particularly from the point of view of evaluating dredged materials.

Key words: TIE, equilibrium partitioning, sediment toxicity

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Creative Solutions to Dredged Materials Management – The New Jersey Experience

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Faced with a dredged materials backlog of almost 6 million cubic yards and an impending navigational crisis, the State of New Jersey instituted widespread changes on regulatory, legal and policy levels in the way dredged materials are managed throughout the State. Two completely new offices were created to successfully implement this innovative new program, which emphasized dredged materials as a resource rather than a waste. Upland beneficial reuse was essentially unproven, however, and the regulated community was not optimistic about its ability to perform in a manner consistent with project goals and objectives. Over \$250 million in combined funding from the Port Authority of New York and New Jersey and a statewide referendum provided the resources necessary to perform pilot and demonstrations of new technologies. Projects were chosen for testing based on their ability to meet objectives on sediment reduction, contaminant reduction, and beneficial reuse reduction potential. Beneficial use projects were shown to result in not only increased disposal capacity, but also remediation and reclamation of abandoned industrial properties. An extensive contaminant monitoring and source trackdown program is underway to and will result in a plan to reduce the amount of contaminated materials that must be managed. Sediment decontamination technology demonstrations, following the groundbreaking work of the USEPA/WRDA program have been initiated and if successful may provide additional reuse capacity as well as a cost-effective manner for treatment of highly contaminated sediments. The overall progress of these programs will be discussed as well as lessons learned and a blueprint for future efforts.

Key words: beneficial use, contaminated sediments, decontamination, New York/New Jersey Harbor

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Comparative Evaluation of Risks from Alternatives for Dredged Material Management in New York/New Jersey Harbor

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Managers in New York and New Jersey Harbor are developing strategies to dispose and manage large volumes of sediments that must be dredged in order to maintain passable waterways. A number of alternatives are available including aquatic containment facilities, upland containment, treatment, and beneficial reuse. An important consideration in the selection of an appropriate alternative is the evaluation of potential risks to ecological and human receptors. This study presents the results of a prospective screening-level ecological and human health risk assessment that compares risks associated with management alternatives for contaminated dredged materials. The major objectives of the work were to identify exposures that show the potential for risk and cause for concern, develop a framework for a comparative risk assessment, and compare relative potential risks among eight management alternatives. The results can be used by managers to identify specific characteristics of the placement/treatment alternatives that may increase the potential for risk, choose one alternative over another for sediments with high concentrations of certain contaminants, implement controls that mitigate risk, or identify the need to a more comprehensive site-specific risk assessment.

Key words: New York/New Jersey Harbor, risk assessment, management

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The Capping Proposal for Cell 1, Tommy Thompson Park – A Wetland Creation Opportunity on the Toronto Waterfront

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The Confined Disposal Facility (CDF) for the Port of Toronto is operated by the Toronto Port Authority and consists of three disposal cells (49 ha. in size), within Tommy Thompson Park (TTP). Tommy Thompson Park is a spit of land on the central Toronto Waterfront that extends southwest into Lake Ontario for 5 km. Since 1982, the park has been the repository for sediments dredged from the mouth of the Don River and other locations within the Toronto Harbour.

Dredging and disposal operations were approved under the Provincial Environmental Assessment Act, subject to a number of conditions. One condition dictates that the cells within the CDF "be topped off and capped in a manner which restricts biological uptake and mobility of contaminants." The Toronto and Region Conservation Authority (TRCA) is the government organization responsible for determining the long-term use of the CDF site. Following extensive studies of the existing environmental conditions within Cell 1 and after evaluation of the economic and engineering considerations of the project, the TRCA and the Toronto Port Authority is proposing the use of a sub-aqueous clean-fill cap and wetland creation at the site.

To test the feasibility of a cap and wetland the TRCA developed a similar proposal for the Triangle Pond area within TTP. The triangle pond is a one-hectare water body centrally located within the park that was constructed in the early 1970s to test the feasibility of developing a large scale CDF for the harbour. The capping construction was completed over the course of six months in 1999 and a variety of wetland vegetation has been established through plantings and colonization over the past growing season.

The wetland at Triangle Pond and our proposed wetland at Disposal Cell one will enhance opportunities for public education and recreation, wildlife habitat improvement, and increase ecosystem diversity. In addition, our use of a Clean-fill/Wetland at Tommy Thompson Park may demonstrate what can be achieved in the way of wetland creation at other Great Lakes CDFs.

Key words: wetland creation, CDF, Great Lakes, capping, Toronto

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Geotextile Contained Contaminated Dredged Material, Marina Del Rey, Los Angeles and Port of Oakland, California

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Approximately 42,000 m³ (55,000 cubic yards, cy) of contaminated maintenance dredged material has been successfully contained in geotextile containers and placed with split hull bottom dump barges in a shallow water habitat and capped with a layer of clean sandy dredged material. The dredged materials contained about 7 to 8 percent fine grained soil and were contaminated with lead, zinc and copper. The materials were mechanically dredged with a clamshell bucket and placed in geotextile containers. The containers were sewn closed and placed within the Port of Los Angeles' (POLA) Shallow Water Habitat (SWH) Confined Aquatic Disposal (CAD) site. Forty-four geotextile containers were filled with an average of about 992 m³

(1300 cy) of contaminated maintenance dredged material from the Marina Del Rey, California, channel entrance and the Ballona Flood Control Channel, Los Angeles, California. Dredging began November 10, 1994 and was completed December 18, 1994. An average of 1.5 containers or 1527 m³ (2000 cy) were placed each day using a Differential Global Positioning system. This was the first project of its kind in the world where contaminated dredged material was successfully contained in geotextile containers, placed, and capped with a sand layer.

At the same time as the Marina Del Rey project, the Port of Oakland, California, was in mechanically excavating contaminated maintenance dredged material into a holding barge and then pumping it into geotextile tubes for dewatering and subsequent landfill disposal.

Geotextile tubes were successfully filled with contaminated dredged material and allowed to drain to about 40 to 65 percent of their original volume prior to landfill placement.

As a result of these two demonstration projects, there are several similar projects being designed by the New York-New Jersey Port Authority, New York, New York and the Massachusetts Port Authority, Boston, Massachusetts. These new and innovative concepts of containing contaminated dredged material in geotextile containers have proven to be constructably practical, technically and economically feasible and environmentally acceptable compared to other disposal alternatives.

Key words: geotextile containers, split hull bottom dump scows, shallow water habitat, CAD, Los Angeles, Oakland, Marina Del Rey, CA

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Dredged Material Filled Geotubes, San Antonio Inlet Containment Island, Buenaventura Bay, Colombia

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One of the first Geotube applications in Colombia was for construction of confined disposal area islands that will be used for containment and dewatering of fine-grained maintenance dredged materials. The project is located on the San Antonio Inlet, Buenaventura Colombia. The dredged material containment area is the first of two oval shaped islands planned in this riverine and tidal environment. This new and innovative construction methodology involved hydraulically filling geotubes with a sandy fill material. Geotubes are simply an assemblage of geotextile fabric panels sewn to form long tubes for containment of dredged material. The geotubes were positioned end to end to provide a perimeter dike for dredged material containment in tidal variations of 4-meters twice a day. After the oval shaped islands are completed they will serve as dredged material containment facilities until they are filled and stabilized. After they are stabilized they will be planted in Mangrove trees and other native vegetation and will be used exclusively for environmental purposes.

Key words: containment, geotextile tubes, beneficial use, San Antonio Inlet, Columbia

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Beneficial Use of Dredged Sediments as a Feedstock in Conventional Portland Cement Production

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Sediments contain a significant amount of a valuable commodity that is actively mined in this country on a massive scale: quartz (SiO₂). With rapidly depleting natural quantities of SiO₂, industries like the Portland cement manufacturing industry are constantly seeking alternative sources. Against this background, the primary goal of the sediment management approach being proposed is to capitalize on the inherent properties of dredged sediments to produce a valuable and marketable commodity: Portland cement (Portland cement is an extremely fine, gray powder manufactured from some of the earth's minerals. After mixing with water, Portland cement is the glue that binds sand and gravel together into the rock-like mass known as concrete).

This research project is progressing along two fronts: First, study of cement manufacture using contaminated sediments as a partial feedstock is being conducted, and the resulting cement characteristics are being investigated. Second, the fate of organic and inorganic contaminants initially present in the sediments is being investigated, particularly the mineralogical form of heavy metals that remain in the cement matrix and the concomitant leaching properties.

This presentation will focus on the justification for this approach, including an economic analysis that will highlight the conditions (e.g. transportation situation, tipping fees, sediment water content) for which this approach may be feasible. Preliminary cement mix ratios, cement quality, and pH-dependent leaching results will also be presented based on work using sediments from New York Harbor.

Key words: sediment, beneficial use, cement

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Siting a Confined Disposal and Treatment Facility within a Regional Framework for Managing Contaminated Sediment: Lessons Learned and Remaining Challenges

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The need for a comprehensive sediment management program in the Puget Sound region was recognized more than twenty years ago. A cooperative program to effectively manage cleaner dredged material was established in 1988. Sediment management standards promulgated in 1991 define requirements for cleaning up contaminated sediment and controlling continued discharges. However, remediation of contaminated sites identified since 1996 has often been delayed because of inadequate regional confined disposal capacity.

Seven federal, state and quasi-public parties are now participating in a joint effort to site and build regional capacity to manage contaminated dredged material by a combination of beneficial uses, treatment and disposal. Thus, challenges encountered in the multi-user disposal site or "MUDS" project include funding feasibility studies, reaching consensus on technical and policy issues, generating public interest prior to choosing preferred types of facilities and sites, and identifying a willing facility owner. Many of these challenges have been or are in the process of being resolved, but other significant hurdles remain. Key issues remaining include demonstrating a reliable flow of contaminated material, identifying methods to accelerate cleanup activities, determining the appropriateness of using public lands for aquatic disposal and evaluating the long-term safety and liability of products manufactured from sediment treatment processes.

The authors also describe the need to create a public entity with all the legal authorities needed to form a partnership with one or more private companies to develop confined disposal and treatment capacity. This "MUDS authority" will need to cooperatively define the optimum

partnership, secure adequate funding, obtain technical and policy assistance, generate legislative interest and public acceptance in order to select, design, build and permit a regional facility.

Key words: confined disposal, contaminated sediment, treatment, Puget Sound

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ETHEC Contaminated Sediment Treatment

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ETHEC technology integrates electrical, thermal, and chemical techniques for economical treatment and recycling of contaminated marine sediment, hazardous sludge or water/solid compositions. Contaminated and hazardous waste are used, as a raw material for ETHEC's products manufacturing and are cleaned up using energy accumulated in the processed materials and system. During this process ETHEC cleans up and recycles the waste material and also the contaminants themselves (*i.e.* integrated organic and/or inorganic contaminants). ETHEC modular systems are configured for one stage, two stage, or three stage operation.

During stage 1 ETHEC efficiently concentrates on water the solid residue by extracting water in vapor form from marine sediment. During Stage 2 the solidified, organically contaminated residue, is cleaned up using, again, thermal energy for extracting the organics in vapor. Hazardous organics, such as PCBs, dioxin, carbon disulfide, etc. are vaporized for further treatment. Nonhazardous petroleum-based organics are condensed into fuel products. During Stage 3 the heavy metals are stabilized by a thermo-chemical reaction, as a result of high temperature processing. High temperature heating is a part of ETHEC manufacturing process that converts organic-free sediment (solid) into baked construction filler, or cementitious (pozzolanic) material. The vaporized hazardous organics are on-site thermally decomposed into industrial chemicals.

Environmental benefits includes both on-site waste

processing, and in-line recycling of the treated material and contaminants provide the zero-discharge operation. Integrating the ETHEC systems into industrial-type production lines, using waste heat, as energy source, and using closed loop system configuration prevents pollution.

Application may include contaminated marine sediment, technological sludge, ground water and soil, wastewater, and mineral solid waste compositions.

Depending on the required beneficial products, the necessary ETHEC stages are the following:

- Stage 1: concentrated solid residue, distilled water: dewatering (volume reduction)
- Stage 2: organics free solid (soil): vapor extraction and recovery of nonhazardous organics
- Stage 3: baked fill and aggregate materials, cementitious (pozzolanic) material, industrial chemicals: thermo-chemical stabilization of heavy metals and thermal decomposition of hazardous organics.

Key words: hazardous cleanup, recyclable, treatment

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Identification and Evaluation of Stressors in Toxic Sediments and Dredged Materials

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Identification of stressors in aquatic systems is critical to sound assessment and management of our nation's waterways for a number of reasons. Identification of specific classes of toxicants (or stressors) can be useful in designing effective sediment remediation methods and reasonable options for sediment disposal. Knowledge of which stressors affect benthic systems allows managers to link stressors to specific dischargers and prevent further release of the toxicant. In addition, identification of major causes of toxicity in sediments may guide programs such as sediment quality guidelines and pesticide registration, while knowledge of the causes of toxicity which drive ecological changes such as community structure would be useful in performing ecological risk assessments. To this end, the US Environmental Protection Agency has developed tools (Toxicity Identification and

Evaluation (TIE)) that allow researchers to characterize and identify chemical causes of acute toxicity in sediments and dredged materials. Development of these methods for both interstitial waters and whole sediments is nearly complete, and a guidance document is expected by the end of 2001.

To date, most sediment TIEs have been performed on interstitial waters. Preliminary evidence from the use of interstitial water TIEs reveals certain patterns in causes of sediment toxicity. First, among all sediments tested, there is no one predominant cause of toxicity; metals, organics and ammonia all play a role in about equal amounts in causing toxicity. Second, within single sediment there are usually multiple causes of toxicity; not just one chemical class is present. Finally, if sediments are divided into marine or freshwater sediments, TIEs performed on freshwater sediments indicate a variety of toxicants in fairly equal proportions, while TIEs performed on marine sediments have identified only ammonia and organics as toxicants, with metals playing a minor role. However, it is necessary to keep in mind that a very small number of interstitial water TIEs have been performed, and these trends may change as larger numbers of TIEs (both interstitial and whole sediment) are performed.

Results from interstitial water TIEs will be discussed. Methodology and results from whole sediment TIEs will also be discussed along with advantages, limitations and application of these methods.

Key words: toxicity assessment, methodologies, TIE

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Model of PAH and PCB Bioaccumulation in *Mya arenaria* and Application for Site Assessment

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In areas of sediment contamination, quality guidelines are often used for remediation and/or restoration decisions. To supplement each set of sediment quality guidelines, bioaccumulation models have been used to estimate higher trophic level contamination. Although various models address the bioaccumulative property of contaminants, none are both accurate and easily implemented. To address this issue, a new bioaccumulation model for polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) from sediment to *Mya arenaria* was developed. Basic equilibrium partitioning theory, *i.e.* contaminant partitioning between organism lipid and sediment organic carbon (Bierman 1990) was used as the model foundation. The model was then augmented by adding PAH and PCB partitioning into mollusc protein and PAH partitioning into the sedimentary soot fraction. Data on the PCB and PAH concentrations in sediment and *M. arenaria* from Massachusetts Bay, along with estimates of animal protein and sediment soot content were used to test this new model. The model predicts PCB concentrations in *M. arenaria* with only a slight variation from observed data. Predicted PAH concentrations are more accurate than concentrations predicted by other model types, but organism burdens still remain slightly greater than observed concentrations. To determine its accuracy, the model should be tested with data sets in which all parameters are measured.

Bierman, V. 1990. Equilibrium Partitioning and Biomagnification of Organic Chemicals in Benthic Animals. *Environmental Science and Technology* 24(9):1407-1412

Key words: bioaccumulation model, PAH, PCBs, *Mya arenaria*, site assessment, equilibrium partitioning

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Risk-Based Decisions for Dredged Materials Management: Consideration of Spatial and Temporal Patterns in Exposure Modeling

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This paper addresses the interactions of various aspects of foraging behavior, habitat characteristics, site characteristics, and the spatial distribution of contaminants in developing exposure of winter flounder to polychlorinated biphenyls (PCBs) from a hypothetical, open water dredged material management site in the coastal waters of New York and New Jersey (NY-NJ). It then considers the implications of these interactions on human health risk estimates for local recreational anglers who fish for and eat those flounder. We also address the advantages of such spatially explicit modeling in environmental decision making at dredged material management sites.

The models implemented in this study are a spatial model to account for realistic exposures and a probabilistic adaptation of the Gobas bioaccumulation model that accounts for temporal variations of concentrations of hydrophobic contaminants in sediment and water. We estimated the geographic extent of a winter flounder subpopulation offshore of NY-NJ based on the species biology and its vulnerability to local recreational fishing, the foraging area of individual fish, and their migration patterns. We incorporated these parameters and an estimate of differential attraction to a management site into a spatially explicit model to assess the range of exposures within the population. The output of this exposure

model, flounder PCB tissue concentrations, provided exposure point concentrations for an estimate of human health risk through ingestion of locally caught flounder. The analysis shows that for the model to obtain median risks close to the prediction for the spatially non-explicit case, all spatial parameters would have to be taken at conservative extremes simultaneously. This practice "defaulting" to certain conservatism in the face of uncertainty ill serves the decision-making process. Consideration of realistic spatial and temporal scales in food chain models can help support management decisions regarding dredged material disposal by providing a quantitative expression of the confidence in risk estimates.

Key words: spatial model, PCBs, flounder, New York/New Jersey Harbor

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Capping Efficiency for Metal-Contaminated Marine Sediment under Conditions of Submarine Groundwater Discharge

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Theoretical estimations and laboratory studies suggest that capping can effectively retard contaminant transport under undisturbed conditions. However, contaminated near-shore areas, commonly selected as capping sites, are frequently subjected to Submarine Groundwater Discharge (SGD). Four columns were set up in the laboratory to simulate metal transport through sediment and capping material in the presence and

absence of SGD. In the absence of SGD, capping enhanced Mo flux and initial Mn flux while having no effect in retarding Fe flux, presumably due to altered redox conditions. This effect was more pronounced in the presence of SGD (4.7×10^{-4} m/hr specific discharge). Capping enhanced Cd flux and initial fluxes of Ni, Cu, and Zn under conditions of simulated SGD, which may be caused by co-transport with Mn and Fe and oxidation of sulfide. Capping retarded Cr and Pb fluxes and steady-state Ni, Cu, Zn, and Fe fluxes in the presence of simulated SGD. However, capping efficiency decreased relative to no SGD. Elevated Mn concentration was detected at the capping surface with simulated SGD. Results indicate that advective flow may lead to significantly higher metal fluxes than under undisturbed conditions.

Key words: capping, metals, submarine groundwater discharge

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Evaluation of Environmental Effects on Metal Transport from Capped Contaminated Sediment under Conditions of Submarine Groundwater Discharge

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Previous studies conducted in our laboratories have shown that submarine groundwater discharge (SGD) can significantly increase metal fluxes from capped contaminated sediment to the overlying water. Five columns were set up in the laboratory to evaluate the effects of groundwater pH, sediment depth, and groundwater flow rate on metal transport from capped contaminated sediment under conditions of SGD. Acidified groundwater discharge was shown to enhance the mobility of all tested

metals except Mo. Although much of the released metal was adsorbed by the capping material, increased metal fluxes to the overlying water were observed for Ni, Cu, Zn, and Pb. Additional sediment depth enhanced fluxes for all tested metals except Cd and Pb. Increased SGD rates did not significantly change the steady-state volume-normalized fluxes for all the metals except for Cr and Mo. However, all metal releases were higher due to the greater flow at increased SGD rates.

Key words: metal transport, capped sediments, submarine groundwater discharge

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Numerical Sediment Quality Guidelines: How Well Do They Accurately Predict Acute Toxicity and Benthic Effects in Saltwater?

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Data were compiled from chemical analyses and acute toxicity tests of 1513 saltwater sediment samples to evaluate the performance of empirically-derived sediment guidelines. The purpose of the study was to objectively quantify the degree to which sediment guidelines accurately predicted either toxic or non-toxic responses in laboratory tests. Data were analyzed to both determine the percentages of samples in which acute toxicity was observed and calculate average survival within ranges in the numbers of sediment quality guidelines (SQGs) exceeded and mean SQG quotients. Within four ranges in contamination, the percentages of samples that were toxic were: <10%, 20-30%, 50-60%, and 75%. Average percent amphipod survival in the same samples decreased sequentially from 92%, to 79-88%, to 59-70%, and to 37-46%. Numerous other data sets were compiled to also determine how frequently benthic infaunal communities were altered when the SQGs were exceeded. The data analyses indicated that adverse alterations to the infauna occurred at concentrations approximately an

order of magnitude lower than those associated with acute toxicity. Therefore, the data indicated that numerical guidelines for saltwater sediments are useful in estimating the probabilities that future samples would be toxic either in laboratory tests or in nature.

Key words: sediment quality guidelines, contaminated sediments, sediment toxicity, benthic infauna

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Consolidation Settlement of Dredged Sediment in a Confined Disposal Facility

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As part of a study of the Newark Bay Confined (aquatic) Disposal Facility (NBCDF), numerical analyses of the consolidation settlement of the deposited sediment were performed and the results compared to actual settlement data. The consolidation parameters for the sediments were estimated using existing data for sediments from dredged sites within the New York and New Jersey port area and by inference from measurements of the in situ void ratios of the placed sediment in the NBCDF. In addition, approximate analyses were performed using Terzaghi's Fourier series solution for one-dimensional rate of consolidation of a single, homogeneous soil layer.

In the approximate analyses, the effect of large strain on the rate of consolidation of the layer of placed sediments was accounted for using the suggestion by Olson (1998), for which he obtained close agreement between Terzaghi's Fourier series solution and a numerical solution. Nonlinear compression was taken into account by using the void ratio versus effective stress relationship, taken for the sediment, directly and thus introducing no additional error into the analysis. The coefficient of consolidation (cv) versus effective stress

was calculated from the permeability versus effective stress and the void ratio versus effective stress relationships taken for the sediments, and a suitable "average" value of cv was used for the approximate analysis.

The settlement data and both the numerical analysis results and the approximate analysis results are similar in magnitude. Comparison of the data and the results is used to discuss the degree of accuracy obtainable in prediction of settlements of sediments deposited below water.

Key words: consolidation, confined aquatic disposal facility, New York/New Jersey Harbor, CDF

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Design and Permitting of a Nearshore Confined Disposal Facility in Portland, Oregon

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The Columbia and Willamette River Systems of Oregon and Washington support a variety of commercial and recreational navigational interests including deep-draft access to the ports of Portland, Oregon and Vancouver, Washington. In this metropolitan area of approximately 1.5 million people, there are more than fifty marinas with moorage for thousands of vessels and numerous point and non-point source discharges of waste water and storm water run-off that impact sediment and water quality. Over the 100 years of river usage, pollutants from these sources such as heavy metals, petroleum hydrocarbons, pesticides, herbicides, organo-tins, polychlorinated biphenyls (PCBs), volatile and semi-volatile organic compounds have rendered certain sections of this watershed potentially harmful to human health and the environment. This has led to the proposed listing of a 6.5 mile section of the Willamette River known as the Portland Harbor under the U.S. Environmental Protection Agency's (USEPA) Comprehensive Environmental Response,

Compensation, and Liability Act (CERCLA, a.k.a. Superfund program.) In addition, the National Marine Fisheries Service (NMFS) has recently listed as threatened under the Endangered Species Act (ESA), several species of salmonids that utilize this vital watershed. These events, along with ever increasing public awareness have set forth a genuine need for viable solutions to maintain the navigational and ecological integrity of the region.

This paper addresses the history of events in Oregon and what has lead to the planning of a nearshore confined disposal facility (CDF) and the process (legal, technical, political) that is currently being undertaken. The site is a 22-acre island parcel originally excavated for the construction of a marina. The proposed CDF design will provide a disposal capacity of approximately 1.2 million cubic yards of non-hazardous contaminated sediments dredged from the Columbia and Willamette Rivers. The challenges of locating and permitting a CDF in a state that has never had one and in a freshwater environment where effects based sediment quality criteria have not been established are formidable. Design efforts have included containment berm seismic stability improvements, and the use of a geosynthetic clay liner (GCL) installed in 20 to 25 feet of water as additional security to prevent contaminant migration off-site. The completed CDF will be capped, contoured, and revegetated as open space and riparian habitat.

Key words: contaminated sediments, site selection, CDF, capping, Portland, OR

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Managing PCB Emissions from Contaminated Sediment Remediation Operations: A Risk-Based Chronic Exposure Budget Approach for Protecting the Public

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The remediation of contaminated sediments is often accomplished by dredging the contaminated material and transporting it to a confined disposal facility. While these actions lead to a long term improvement in the quality of the local sediment and surface water, a short term increase in ambient air polychlorinated biphenyls (PCBs) concentrations may result during the implementation of the remedial construction activities. Volatile PCB compounds and congeners may be released during dredging, materials handling and transport, dewatering and water treatment, and disposal facility filling operations. These releases contribute to increased ambient air concentrations above background levels at downwind locations where residents or commercial workers in the public may be exposed. The airborne concentrations at the points of public exposure are influenced by: the type, magnitude, timing and spatial distribution of the emission sources (e.g., dredges and disposal facilities); the level of sediment contamination present; and the local meteorology and air dispersion patterns between the sources and the public receptors. Maximum ambient concentrations of airborne PCBs may be calculated to meet target risk goals given prescribed exposure and remediation production scenarios. Taken together, calculated risk-based exposure point concentrations may be combined with local dispersion behavior to develop a cumulative exposure budget relationship that can be compared to actual monitoring data to ensure that air concentrations at public exposure points would not exceed risk-based target values over the course of the project. This relationship can be identified for different points in time as the location of dredging operations and the quality of the

contaminated sediments change. A program of air action levels, monitoring objectives, and management triggers and required responses that is built around such a chronic exposure budget can be demonstrated to be protective of all members of the potentially affected public. An approach for establishing a program for risk-based management of PCB emissions from contaminated sediment remedial construction activities is presented and discussed.

Key words: air action levels, PCBs, sediment, risk management, air monitoring

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Alternative Approaches to Sediment Toxicity Testing: Reverse-TIE and Critical Body Residues

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The presence of contaminated sediments in urban harbors raises management concerns with regards to dredging and dredge disposal, seafood safety, and the health of aquatic organisms. Elevated levels of a wide range of persistent organic contaminants and a handful of metals have been documented nationwide, yet many of these compounds have limited bioavailability. Determining which chemicals in urban sediments are contributing most to toxic effects will help focus enforcement and source reduction activities. There are a number of approaches for evaluating sediment toxicity. Methods that involve selective removal of contaminants (*i.e.*, ammonia, selected metals, relatively hydrophobic organic contaminants) are typically referred to as toxicity identification evaluation (TIE), and have been most frequently employed in effluent testing. More recently the TIE approach has been extended to evaluate sediment pore water or whole sediments (*e.g.*, mixing of sediment with selective sorbent materials). Pore water TIE tests have fundamental limitations for highly bioaccumulative chemicals such as hydrophobic organic chemicals

(HOCs) and mercury. The small solution volumes typically used in static pore water assays severely limit the exposure concentrations of contaminants with bioconcentration factors (BCFs) of $>10^3$ - 10^4 . Under these conditions, most of the contaminant in solution is quickly accumulated by the test organisms. Exposure levels may be lowered further by contaminant loss to volatilization or sorption to container surfaces. Whole sediment TIE methods have only recently begun to be developed. In this paper we discuss recent work taking two alternative approaches to sediment toxicity assessment. In the first we used Amberlite resins to isolate easily desorbable HOCs from highly contaminated urban sediment. This material was then amended this material onto reference sediment to assess toxicity using tests with the amphipod *Ampelisca abdita*. We term this approach "reverse-TIE" as instead of inferring toxicity by selective removal of contaminants as in done in conventional TIE, the actual toxicity of specific fractions can be tested directly. Another advantage of this approach is that material isolated can be chromatographically separated into compound or compound-class specific fractions, and these testing independently. A second approach employing a micro-extraction techniques measuring critical body residues (the body burden of contaminant at 50% mortality, LD50) was also used to assess sediment toxicity. In these experiments, LD50s for *Ampelisca* exposed to a suite of standard organic toxicants were compared with contaminant body burdens in animals exposed to sediments from U.S. Environmental Protection Agency's (USEPA) Regional Environmental Monitoring and Assessment Program (REMAP) study of the New York/New Jersey Harbor Complex in 1998. The results of this work provide insight on which chemical classes may or may not be causing toxicity observed in standard tests with New York/New Jersey Harbor sediments, and provide promising approaches that compliment more traditional approaches to sediment toxicity evaluation.

Key words: sediment toxicity, toxicity assessment, TIE

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The Use of Sediment Trend Analysis (STA®) in Dredged Material Management

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Sediment trend analysis (STA) is a technique that enables patterns of net sediment transport to be determined by relative changes in grain-size distributions of all naturally occurring sediments. In addition, STA can determine the dynamic behavior of bottom sediments with respect to erosion, accretion or dynamic equilibrium. Invented by GeoSea Consulting, STA has been used in dredging and harbor management concerns in over 70 projects worldwide. The data requirements are sediment grab samples collected at a regular spacing that is determined by the area under consideration. The samples are analyzed for their complete grain-size distribution using a laser technique. Transport pathways are then determined by searching for sample sequences whose distributions change according to the "rules of transport."

STA has been particularly useful in many dredged material management issues including (i) locating disposal sites to minimize environmental impact, (ii) predicting the fate of dredged material, (iii) locating confined aquatic disposal (CAD) sites to ensure minimum disturbance, (iv) providing alternative routes for navigation channels to minimize dredging, (v) directing numerical models (vi) planning habitat restoration projects, (vii) assessing remediation options for contaminated sites, and (viii) providing a fundamental data base for all environmental concerns. This talk will describe briefly the theory of STA, which will then be followed by a presentation of a number of specific studies undertaken in Europe, Canada and the United States demonstrating its use in all the above described dredged material management issues.

Key words: sediment transport, dredged material management, trend analysis

Detrimental Effects of Sedimentation on Marine Benthos: What can be Learned from Natural Processes and Rates?

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Sediment movement, erosion, and deposition are natural processes to which benthic organisms are adapted. Benthic infauna burrow upwards and downwards with these events to maintain an ideal position in the sediment. Laboratory studies have cataloged the range of responses to flow and sediment movement that allow benthos to survive under intense storm-generated conditions including resilience to sandblasting by bedload transport.

Sedimentation patterns are often altered significantly with commercial and recreational modifications of the marine environment. While the scales of these alterations greatly exceed that of natural occurrences, there is little quantitative information vital for predicting how materials placement will affect the ecology of these environments. If biological effects are appropriately parameterized, is it possible to predict disturbances and to design management projects that will minimize these disturbances while still maximizing the benefits?

In Delaware Bay, we are using several approaches to determine what rates and frequencies of sediment movement are natural events, and further, what rates and frequencies are detrimental to representative benthic species, developmental stages and functional groups. Transects for determining erosion and deposition rates were established at four beach sites along lower Delaware Bay. Concurrently, we are using a lab approach to establish what sedimentation rates and frequencies are detrimental to infauna, epifauna, and functional groups. Laboratory burial experiments include measurements of limiting depth and frequency of sedimentation. We are also investigating the susceptibility of the Bay's hard-bottom epifauna to natural disturbances using side scan sonar and a laboratory water tunnel.

These results are intended to address the ecological aspects of dredge materials placement and site selection. Quantifying natural sedimentation rates and the

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susceptibility of macrofaunal functional groups is one approach towards predicting environmental impacts. If materials placement can be planned to be analogous to natural events, then community responses will follow natural seasonal and successional trends. When sedimentation exceeds natural thresholds, ensuing impacts will likely involve total loss of the community and subsequent colonization by pioneer species. Thus an entirely different suite of ecological processes will drive impacts and recovery, potentially leading to dramatically altered benthic communities.

Key words: sedimentation, erosion, Delaware Bay, site selection, benthic community

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Confined Disposal Facilities (CDFs): Great Lakes Experience

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Confined disposal facilities, or CDFs have been used for the management of dredged material from Great Lakes sites that is contaminated and not suitable for open water disposal. Confined disposal is used for about one-half of the sediments dredged to maintain Great Lakes navigation channels, which is approximately 2 million cubic yards per year. Forty-four CDFs have been constructed by the Corps of Engineers in cooperation with state and local partners to manage contaminated sediments from Great Lakes ports and channels since the late 1960's. Confined disposal has also been used at the vast majority of sediment remediation projects around the Great Lakes, of which there have been about 40 in the past fifteen years.

The Great Lakes CDFs have had their share of controversy. Among the most common environmental concerns raised about CDFs are the significance of long-term releases of contaminants through CDF dikes and the biouptake of contaminants by plants and animals that inhabit the CDFs. The U.S. Army Corps of Engineers

(USACE) and U.S. Environmental Protection Agency (USEPA) have collaborated on several interagency working groups and special studies to address public and agency concerns about contaminated sediment management and CDFs. These studies included contaminant loss modeling, biomonitoring and risk analysis. Federal and state agencies have partnered to form the Great Lakes Dredging Team, which is facilitating public outreach on regional dredging issues and actively promoting the beneficial use of dredged material as an alternative to new CDFs. The USACE and USEPA are conducting a number of demonstrations of technologies to reclaim beneficial materials from Great Lakes CDFs.

The USACE and USEPA are currently working on a joint report to Congress on Great Lakes confined disposal facilities. This report will summarize the history of the CDF program, coordination, outreach, and special investigations, and provide an analysis of the overall impacts of these facilities on the Great Lakes environment.

Key words: CDF, Great Lakes

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Toxicity Testing, Risk Assessment, and Options for Dredged Material Management

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The U.S. Environmental Protection Agency (USEPA), in conjunction with the U.S. Army Corps of Engineers (USACE), has lead responsibility for developing guidelines that provide environmental criteria for evaluating proposed discharges of dredged material into

U.S. waters. To comply with these guidelines, proposed discharges must: a) present the least environmentally damaging, practicable management alternative; b) comply with established legal standards; 3) not result in significant degradation of the aquatic environment; and 4) utilize all practicable means to minimize adverse environmental impacts. In the "Inland Testing Manual" (ITM) and the "Green Book", the U.S. Environmental Protection Agency (USEPA) and U.S. Army Corps of Engineers (USACE) described a testing and analysis protocol to be used to evaluate whether guideline criteria are met for dredged material disposal in inland waters and open ocean waters, respectively.

The evaluation programs described in the ITM and Green Book were designed to support informed management decisions about the placement of dredged sediments. They specify a tiered testing and evaluation approach that includes performance of bioassays to assess toxicity of the dredged sediments to species inhabiting the disposal site. Both water column and bedded sediment toxicity tests are incorporated, and sediment bioaccumulation tests are specified when bioaccumulative chemicals are present in the dredged material at sufficiently high levels. Early tier toxicity tests focus on acute responses, whereas later tier testing (when required) can employ longer test exposures and sublethal endpoints. In all cases, the toxicity of dredged material proposed for disposal is evaluated against toxicity measured in a suitable reference sediment. As part of this talk, we will describe toxicity tests currently used in dredged material evaluations, and will suggest ways to improve the battery of tests.

Although current U.S. evaluation protocols incorporate both exposure (sediment chemistry and bioaccumulation) and effects (toxicity) components, and therefore reflect to some degree the toxicological risks associated with disposal activities, the focus of analysis activities is limited to the sediments of each dredging project separately. Thus cumulative risks to water column and benthic organisms at and near the designated disposal site are difficult to assess. An alternate approach is to focus attention on the disposal site, with the goal of understanding more directly the risks of multiple disposal events to receiving ecosystems. Here we review an application of ecological risk assessment that allows specification of disposal site receptors and assessment endpoints, recognition of variation in exposure conditions (including the discharge sequence of sediments from different projects), and consideration of the temporal and

spatial components of risk. When expanded to include other disposal options (upland, wetland), this approach to assessing risks to receiving ecosystems can provide the basis for holistic management of dredged material disposal. This presentation does not necessarily reflect the position or the policy of the USEPA, and no official endorsement should be inferred.

Key words: disposal, toxicity testing, risk assessment, risk management

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Risks of Polluted Sediment Disposal at Sea

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Dredged sediment in the United States cannot be dumped at sea if whole sediment is toxic to test organisms or if certain chemicals are bioaccumulated from it. However, risks to individual human consumers of seafood, risks to individual members of endangered populations, and risks to populations of marine organisms depend more on the location and size of a dumpsite than on intrinsic characteristics of sediment. For example, since an ocean dumpsite occupies less than 0.1% of the area required by a living marine resource, a fish taken at a dumpsite would represent a very small fraction of any person's seafood intake. Such considerations are central to estimates of risk of sewage-sludge applied to gardens and farms, where allowable levels of chemical contamination are well in excess of what is found in dredged sediment, and should apply to sediment disposal. Biological changes at a dumpsite are inevitable just as they are for disposal at any terrestrial or aquatic location. By obvious choice, no site designated for dredged material dumping is in a uniquely important area where, for example, populations congregate to spawn or early life stages find refuge from predation. By recognizing that local biological effects are inevitable and that risks to humans from local contaminant accumulation by fish and shellfish are diminished by the widespread distribution of seafood, judgments on ocean disposal of dredged

material can be based on wider considerations than just characteristics of the material. The crux of the issue is to assess the risk to marine populations and to public health posed by the movement of contamination away from a dumpsite. Biological tests on whole sediment are of little use in that regard.

Key words: contaminated sediments, sediment disposal

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Design Requirements for Contained Aquatic Disposal Pits

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Contained Aquatic Disposal (CAD) is an option for placement of contaminated sediments in existing or constructed subaqueous pits or other features providing lateral containment followed by placement of a cap of clean isolating material. The design of a CAD project requires a specific sequence of evaluations to ensure the project can be contained at the site and that water quality and cap effectiveness is maintained in the long term. Sizing of the pits with respect to volume, excavated depth, surface area and dimensions is a critical design requirement for this option. Constraints with respect to erosion, consolidation, and cap design all influenced the long term effectiveness. A variety of evaluation methods are applicable for CAD design to include laboratory testing of the materials and the application of several types of computer models. This presentation summarizes the recommended design approach for CAD projects to include these considerations:

Site selection - Site conditions have major implications for the design and costs of a CAD option.

Design objectives - An overall design objective for CAD is to provide sufficient volumetric capacity to accommodate the required volume of dredged material and to isolate the material from the aquatic environment.

Geometry - Size and orientation of the depression forming the CAD will influence the storage volume,

ability to retain materials within the site during placement, water quality, and the long-term stability of the site.

Fill sequencing - The sequence of excavation, use of excavated material, placement sequence of contaminated sediment layers, interim and final caps, and long term fill requirements will influence the overall effectiveness of the CAD for contaminant retention.

Placement operations - Conventional discharge from barges, hopper dredges, and pipelines is appropriate for many CAD applications. Diffusers, tremie approaches, submerged discharge, spreading techniques, or other control measures may be considered, but these could substantially add to costs.

Dispersion and retention during placement - The contaminated materials must be placed in the CAD pit such that water column impacts from releases of contaminants during placement are acceptable and the material is effectively retained within the site.

Cap design - The composition and dimensions (thickness) of the cap must be compatible with available construction and placement techniques. Cap design must account for bioturbation, erosion, consolidation, and long term chemical isolation.

Monitoring - Monitoring is required to ensure the design objectives are met and should include physical, chemical, and biological components to address the processes of concern.

Key words: capping, CAD, contaminated sediments, consolidation, modeling

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Dredged Materials and Environmental Restoration: A Win-Win Story?

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The use of dredged material in environmental restoration or rehabilitation programs represents an almost unique circumstance where two types of problems are solved with a single action. The need for dredging may be initially prompted by a societal need for continued or new economic development, while the availability of material for new substrate in or near coasts and waterways can produce environmental effects increasing the overall societal benefit associated with the project. Individual projects can move hundreds of thousands of cubic yards of material and result in hundreds of acres of new or rehabilitated wetlands. In Louisiana, even dredging projects in the Chenier Plain remote from the continually dredged Mississippi River, have created almost 500 acres of wetlands within the last several years. However, such 'beneficial uses' do not come easily and require exceptional cooperation among state, federal and local governmental agencies as well as landowners and others interested in solving environmental problems. The movement of large volumes of sediment from one location to another disrupts existing 'habitats' at both the dredging location and the disposal site. Consequently, the environmental effects must be carefully evaluated in the light not just of the proposed benefit for one particular restoration goal but in terms of the habitats that are lost or replaced by the dredging or material placement.

Dedicated dredging for environmental benefits involves the same kind of trade-offs. While many may recognize the need for greater wetland acreage to offset losses associated with development, commercial harvesters who live from catch to catch will not always accept changes in depth and character of dredged waterbodies as well as increased turbidity associated with dredging activities. Education concerning the long-term need to sustain ecosystems to support harvestable species is frequently seen as the solution – more pragmatically, compensation for losses included as part of project costs may be the best short-term solution.

Despite these challenges to implementation, all over the world, dredged material is being used to rebuild lost substrate, kick-start restoration projects, and provide

habitat for important species. Economic growth and environmental restoration are frequently incompatible objectives in planning and management. Beneficial use of dredged material is an issue where societal and environmental needs can converge – the challenge is in planning material use such that worthwhile environmental projects can be implemented at the time and in the place where the dredging must take place.

Key words: Louisiana, environmental management, planning, Gulf of Mexico

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Beneficial Uses of Dredged Material for Habitat Creation, Enhancement and Restoration in NY/NJ Harbor

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The dredging of ports and harbors is an economic necessity that cannot be avoided. Historically, dredged materials have been used as fill to create upland habitats or placed offshore. Upon realization that filling aquatic habitats with dredged materials was significantly impacting species abundances and environmental quality, finding acceptable disposal options for dredged material became a top priority. The Dredged Material Management Plan (DMMP) has been initiated by the U.S. Army Corps of Engineers, New York District (USACE-NYD), in cooperation with the Port Authority of New York/New Jersey, to investigate cost-effective

and environmentally acceptable alternatives for the placement and disposal of contaminated and non-contaminated dredged materials. USACE-NYD produced a technical report under the DMMP describing potential beneficial uses of dredged material from the NY/NJ Harbor for habitat creation and enhancement. The advantages, disadvantages, potential volumes, and estimated costs associated with each creation/enhancement option are analyzed. While beneficial use options in NY/NJ Harbor will not consume all of the material being produced by maintenance dredging, the potential of consuming significant amounts of dredged material in the future, while enhancing the overall environmental quality of the Harbor has become a top priority.

Key words: beneficial use, New York/New Jersey Harbor, contaminated sediments

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Pilot In-Situ Capping Project at the Palos Verdes Shelf

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In July 1996, the U.S. Environmental Protection Agency (USEPA) began a Superfund investigation of the 43-square kilometer area of dichloro-diphenyl-trichloroethane (DDT)- and polychlorinated biphenyl (PCB)-contaminated sediments in an area known as the Palos Verdes Shelf near Los Angeles, California. The sediments, termed effluent-affected, are present as a result of discharges from the ocean outfall system operated by the Los Angeles County Sanitation Districts. USEPA's investigation has included an evaluation of human health and ecological risks posed by the DDT- and PCB-contaminated sediments, as well as an evaluation of potential clean-up actions. USEPA looked at a number of options for sediment restoration and identified *in-situ* capping as the most feasible cleanup action that could be taken in the near term to address human health and ecological risks at the site.

As part of its ongoing evaluation of in situ capping,

USEPA undertook a pilot capping project at the site in the summer of 2000. This demonstration project consisted of capping all or a portion of three 0.18 square kilometer (45-acre) cells at water depths ranging from approximately 40 to 60 meters. Two types of cap material were used in the pilot project (a fine-grained sediment and a coarser-grained sand) and a variety of sediment disposal (*i.e.*, cap placement) methodologies were tested.

The overall objective of the field pilot study is to demonstrate that a cap can be placed on the Palos Verdes Shelf and to obtain field data on the short-term processes and behavior of the cap as placed. An extensive environmental monitoring program collected data before, during and after cap placement that will be used by USEPA to address key short and intermediate term questions relative to capping on the Palos Verdes Shelf.

Key words: capping, DDT, PCBs, superfund, Palos Verdes shelf, California

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Sorption and Transport of Hydrophobic Contaminants through Sediment Caps: Incorporating the Effects of Benthic Infauna

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Capping is a commonly used method for confining contaminated sediments. However, quantitative theories for determining optimal cap thickness that include the effects of mixing by benthic organisms are lacking. The goal of this study was to develop a mathematical model to predict the fate and transport of contaminants within a sediment cap due to bioturbation by organisms colonizing the capped sediments. The model was used to predict the cap thickness required to isolate contaminants from

surface sediment and the water column. Benthic biological data collected in Boston Harbor were used to predict the minimum cap thickness required for a capping project in Boston Harbor. The biological data were collected from a sub-tidal site near the capping area that possessed sandy sediments. Thus, the potential existed for the sand caps to be colonized by a community similar to the one at the nearby sampling site.

The model predicted that a 20-cm thick cap would be sufficient to contain hydrophobic contaminants possessing an organic carbon-water partition coefficient (k_{oc}) greater than 106. For contaminants with lower values of k_{oc} , a cap as thin as 5 cm would be sufficient to limit surface sediment concentrations.

Key words: CAD, benthic infauna, Boston Harbor, MA

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Canonical Analysis Benthic Communities in Boston Harbor: Any Changes Since the Initiation of Clean-Up Efforts?

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Steep gradients in sediment type and contaminant concentrations in Boston Harbor have resulted in strong gradients in benthic community structure. Furthermore, contaminant loadings have changed greatly since the initiation of cleanup efforts in 1991. If benthic communities were responding to these environmental changes, we would expect to observe strong temporal changes in the benthos as well.

We have applied a new variation on a statistical technique broadly referred to as canonical analysis to the Massachusetts Water Resource Authority (MWRA) benthic dataset (1991-1998) to examine the spatial and temporal patterns in benthic community structure. The analysis identified the most important environmental factors that

determine the observed spatial patterns. We also found that changes in community structure following the initiation of clean-up efforts have been comparatively small.

Key words: Boston Harbor, MA, canonical analysis, benthic community

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Monitoring PCBs in Benthic Marine Fishery Resources

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Coastal dredging projects are necessary in urban harbors to provide safe navigation for ships used for commerce, national defense and recreation, and to support urban redevelopment projects. These projects typically require disposing of harbor sediments laden with chemical contaminants accumulated from many decades of industrial activity. The process of deciding how, when, and where to dispose of such material is difficult because consideration is needed for multiple environmental and societal concerns including adverse effects of contaminants on fishery resources and habitats, economic impacts to those who derive benefits from these resources, and degradation of ecosystems from pre-existing conditions. Contaminant information for pre-existing resources in areas considered to receive dredge disposal material is necessary to determine disposal safeguards before a project begins.

We used two benthic marine fishery resources, the American lobster and winter flounder, to monitor contaminants and report concentrations of polychlorinated biphenyls (PCBs) in samples collected over the past several years in most Massachusetts bays and two urban harbors. These species accumulate PCBs by eating and living on surface sediment, and provide a picture of existing PCB contamination in many areas. Recent trends show PCB levels have been fairly constant and

relatively low. Both harbors show signs that PCB accumulation is not increasing and possibly declining, a finding consistent with national trends. Assessments such as this can be useful for determining pre-existing conditions at candidate sites for dredge material disposal and aid in the design of control measures necessary to protect fishery resources and their habitat.

Key words: PCBs, lobster, flounder, Massachusetts, site assessment

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Past and Potential Role of Dredged Materials in Wetlands Creation and Restoration in the Pacific Northwest

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Dredged material has not been used extensively for enhancement or creation of wetlands in the Pacific Northwest region, where (1) dredging volumes are comparatively low compared to other regions, (2) deep-water disposal is typically the more economically acceptable practice, and (3) erosive environments threaten long-term sustainability of fill projects. Except where justified for sediment remediation (e.g., capping), habitat creation proposals that involve trade-offs between subtidal and intertidal resources tend to be poorly justified and untested, and the few cases studies have shown the danger of taking single-resource (e.g., fisheries habitat) approaches in dynamic estuarine ecosystems. Several of these case studies illustrate disposal projects intended to provide intertidal or shallow-water habitat, where shallow-water/intertidal habitat for juvenile salmon is typically the primary target. Some dredge material projects in the

region have demonstrated the feasibility of creating or contributing to fisheries habitat, but many have resulted in marginal habitat or even counterproductive ecosystem responses. However, compelling pressures for restoration of tidal wetlands to support recovery of Endangered Species Act (ESA)-listed salmon presents increased opportunities for dredge material use, such as in sediment supplementation of breached-dike restoration projects and beach nourishment. Historically diked estuarine wetlands typically undergo subsidence, which in this region may be on the order of 0.75-1.5 m that will likely require decades to restore the pre-dike marsh plain. Acceleration of marsh revegetation and marsh progradation could be enhanced by thin-layer distribution of uncontaminated dredged sediments to raise the base elevation upon which natural sedimentation can occur. Beach nourishment of marine shoreline restoration sites may also provide the means to enhance or accelerate redevelopment of shoreline drift sectors starved of natural sediment inputs and enhance or restore potential eelgrass (*Zostera marina*) habitat. In all cases, use of dredged material must be used as an intermediate step that will promote natural sedimentation and revegetation processes, rather than as an engineered ecological "endpoint" of questionable sustainability and ecosystem contribution.

Key words: intertidal, habitat restoration, Pacific Northwest

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New Concepts in Ecological Risk Assessment: Where Do We Go from Here?

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Since the first use of the term ecotoxicology in 1969, this science has evolved to serve the needs of environmental risk assessment. Although risk assessment involves characterization of both effects and exposures, the dominance of biomedical approaches to hazard and risk assessment resulted in similar uses of single-species

test data as surrogates for the purposes of environmental risk assessment. Through the use of safety factors, this approach was adequate for use in protective hazard assessments and criteria setting but, because it does not consider the presence of multiple species each with a particular sensitivity or the interactions that can occur between these species in a functioning community, it was ill-suited to environmental risk assessment. Significant functional redundancy occurs in most ecosystems but this is poorly considered in single-species tests conducted under laboratory conditions.

A significant advance in effects assessment was the use of the microcosm as a unit within which to test interacting populations of organisms. The microcosm has allowed the measurement of the environmental effect measures such as the NOAEC community under laboratory or field conditions and the application of this and other similarly derived measures to ecological risk assessment. More recently, distributions of single-species laboratory test data have been used for criteria setting and, combined with distributions of exposure concentrations, for risk assessment. Thus, lower percentiles of distributions of species sensitivity values have been used in an a priori way for setting environmental quality criteria such as the FAV, FCV, and HC5. Similar distributional approaches have been combined with modeled or measured concentrations to produce estimates of the joint probability of a single species being affected or that a proportion of organisms in a community will be impacted in a posteriori risk assessments. These approaches have recently been incorporated in new recommendations for ecological risk assessment for pesticides as suggested through the ECOFRAM process.

While some of these developments have addressed risk assessments of toxic substances in sediments, the use of the techniques has not been widely applied for risk assessment of dredged materials. This paper will chronicle these developments in ecotoxicology in the larger framework of the developing science of ecological risk assessment and draw attention to components of the process that could be applied to risk assessment for sediments, dredged material and other similar matrices.

Key words: ecotoxicology, risk assessment

Creating and Restoring Wetlands with Dredged Material: A Summary of Approaches and Issues

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After three decades of experience, environmental managers continue to question the use of dredged material for creation and restoration of wetlands. Different uses of the term "success," poor recognition of the limitations of research design, and poor understanding of wetland development over time (trajectories) have contributed to confusion. Through a series of case studies and summaries of ongoing research, this presentation provides an overview of methods used to create wetlands with dredged material, focusing primarily on standard methods using hydraulically dredged material pumped through pipelines but also covering other methods, such as thin-layer placement. Case studies illustrate innovative approaches to working within the context of natural geomorphology, creation of tidal creeks and pools, and construction of protective structures. Data from a number of sources show that some characteristics of dredged material wetlands are indistinguishable from those of nearby natural wetlands, while other characteristics are clearly different. Data from recently completed studies show that trajectories of increased similarity over time between dredged material wetlands and natural wetlands can be observed for some variables and under some circumstances, but not for others. Information from this presentation is intended to improve understanding among natural resource managers, biologists, planners, and engineers involved with dredged material wetland projects.

Key words: habitat restoration, methodology

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Availability and Biotreatment of Polycyclic Aromatic Hydrocarbons in Sediments

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This work applied new investigative techniques to assess the locations, distributions, and associations of polycyclic aromatic hydrocarbons (PAHs) in dredged harbor sediment. Dredged materials from the Milwaukee Confined Disposal Facility were collected and homogenized to provide sufficient sample for four month bioslurry treatment testing and for PAH analyses on various size and density fractions before and after biotreatment. Sediment PAH analyses included both whole-sample measurements and, most importantly, the determination of PAH distribution by sediment particle size and type. Physicochemical analyses included room temperature Tenax bead aqueous desorption experiments and thermal program desorption-MS studies to assess PAH binding energies on sediment particle types. Thermal programmed desorption-MS experimental protocols and data reduction techniques were developed to evaluate apparent PAH binding activation energies on sediment particles. Microbial ecology testing used polar lipid fatty acid (PLFA) and DNA procedures and radiolabel microcosm studies. Earthworm bioassays studied the acute toxicity effects and PAH bioaccumulation from untreated and biotreated PAH-impacted dredged materials. Overall, the results were used to synthesize and correlate data to assess the availability and treatability of PAHs in dredged sediments.

The significant findings of this work were: the release of PAHs is dependent both on PAH molecular weight and the character of the sediment sorbent material; two principle sediment particle classes dominated the distribution and release of PAHs - clay/silt and coal-derived; PAHs were found preferentially on coal-derived particles; clay/silt particles released PAHs more readily than coal-derived particles; bioslurry treatment reduced

PAHs on the clay/silt fraction but not the coal-derived fraction; PAH reduction in clay/silt fractions by biotreatment resulted in significant reduction in earthworm PAH bioaccumulation; PAHs on coal-derived particles were associated with high binding activation energies; and changes in the phenotype and genetic potentials of the extant microbiota can be used to assess intrinsic biodegradative potential. The benefits of this work include: improved assessment of toxicity and risk for PAH contaminants in sediments by use of particle-scale techniques to assess PAH distribution and behavior; improved assessment for the potential success of biotreatment through understanding of factors contributing to available and unavailable PAH fractions; improved decision making regarding sediment quality criteria for PAHs and the biotreatment of PAH-impacted sediments; and reduced treatment costs and greater likelihood for reuse of dredged sediments through knowledge of the underlying processes affecting PAH locations, availability, treatability, and toxicity.

Key words: biotreatment, contaminated sediments, CDF, PAH

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Use of Seafloor Visualization Tools for Dredged Material Monitoring and Management

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Efforts to evaluate the physical and environmental effects of dredged material placement on the seafloor traditionally have been hampered by the inability to visualize the affected environment. A variety of seafloor monitoring/remote sensing techniques, such as high-resolution bathymetry, sidescan sonar, subbottom profiling, and sediment-profile imaging, have been developed and refined in response to the need for more effective visualization tools. The emergence of Geographic Information Systems (GIS) software for the desktop PC represents a

much-needed advancement in the state-of-the art by facilitating easy organization, manipulation, and widespread access to the results of remote sensing surveys.

The purpose of this presentation is to demonstrate how various sea floor remote sensing techniques, combined with GIS-based visualization tools, have proven effective for monitoring and managing dredged material placement in coastal environments. We will present results from recent studies in which clean sand has been used to cap contaminated dredged material at open-water disposal sites in both New England and New York, as well as results from monitoring the placement and capping of dredged material in in-channel confined aquatic disposal (CAD) cells in Boston Harbor.

Key words: seafloor visualization, dredged material management, monitoring, GIS, CAD

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The Difficulties of Dredging and Placement for Beneficial Use Projects

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The Port of New York and New Jersey's goal of being the Northeast Hub Port for the 21st century will be achieved only if it can provide 15-meter channels to service the new 6000 TEU, and larger, post-panamax vessels. However the Port is naturally shallow (6 meters deep) and must dredge its channels and berths to serve these deep-draft vessels. Annual maintenance dredging requirements are approximately 1.5 million cubic meters (0.9 million contaminated and 600,000 uncontaminated). New channel construction for 12.5, 13.7 and 15-meter projects will require the additional excavation of 7.6 million cubic meters of contaminated sediment, 31 million of clean sediment, and 6.5 million of rock during the next 12 years.

Clean dredged materials, including rock, sand, clay and silts/clays mixtures, are currently used beneficially at the Historic Area Remediation Site (HARS) and at off-shore fishing-reef locations. Contaminated sediments

currently are being beneficially used at upland sites in New Jersey or Pennsylvania or, in some limited cases, disposed at the Newark Bay Confined Disposal Facility. New York is developing an upland demonstration project at the Pennsylvania landfill.

The dredging and disposal processes are changing in character since material has been directed to HARS and upland locations for beneficial use. A number of areas of difficulty have arisen during the dredging and material processing, specifically: regulatory uncertainty, shallow cuts, debris, water management, low production rates, heavy vessel traffic, discontinuous operational requirements and public opposition. These problems are causing dredging costs to rise and project schedules to be threatened. Resolving these and other issues are critical to the Port's ability to deliver the promise of 15-meter channels and to maintain these channels in the future. This paper describes the Port Authority of New York and New Jersey's activities to ameliorate or to resolve each of these difficulties in concert with its dredging contractors and ocean carrier customers.

Key words: beneficial uses, contaminated sediments, disposal, New York/New Jersey Harbor

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Placement of Sediments from Channel Deepening in Sub-Channel Cells

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Historically, about 5.5 million m³ of sediment have been dredged annually to maintain and to improve the navigable waterways and berthing facilities in the Port of New York and New Jersey. Some of these estuarine sediments contain contaminants introduced by upstream or local industrial, municipal, or stormwater discharges. Since 1914, the Port has depended almost exclusively on a single disposal site for placement of its dredged material. This site, the Mud Dump, was located approximately 10 kilometers off the New Jersey Coast. In September 1997,

the disposal site was closed, and a new kind of site was opened — the Historic Area Remediation Site (HARS). Discharges at the HARS are limited to the placement of uncontaminated material suitable for remediating the former disposal site. During this same period, the ships carrying oceanborne cargo have increased in overall size and depth of draft. The requirement to dredge deeper channels to accommodate these new ships is a pressing need for the economic life of the Port.

In order to dredge new channels, however, disposal sites must be identified and available for all excavated material, both HARS suitable and contaminated. The first site to open (1996) was the Newark Bay Confined Aquatic Disposal (CAD) facility for contaminated sediment unsuitable for placement at the HARS. Several upland sites have opened since then that beneficially use the sediment for construction purposes. Approximately 2 million m³ have been placed in upland areas. Beneficial use is the preferred regional approach for placement of dredged materials.

Another potential option, although not a beneficial use option, is the construction of CAD facilities under the channels to be deepened. This approach has been designated the sub-channel cell alternative and is proposed as an option for the Kill Van Kull/ Newark Bay deepening project. Approximately 10 million m³ of material will be removed. The sub-channel cell concept is being investigated as a contingency when beneficial use options are not available or appropriate for contaminated sediment from the project. Initial evaluations suggest that the construction of cells could lower the project cost and shorten the construction time frame over upland options. This paper explores the application of the sub-channel cell concept for providing disposal capacity for channel deepening projects in the Port of New York and New Jersey.

Key words: beneficial use, contaminated sediments, disposal, sub-channel cell, New York/New Jersey Harbor

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Beneficial Use of Dredged Material to Enhance the Restoration Trajectories of Formerly Diked Lands

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Throughout the United States, coastal wetlands are being restored from formerly diked lands, whether salt hay farms, impoundments, or lands drained for agriculture. A common problem with the restoration of these sites is their low elevation associated with long-term lack of tidal inundation and sediment accretion, compaction by heavy equipment, and oxidation associated with exposure to the atmosphere. When sites have been diked for extended periods, elevations may subside by several meters, and with the reintroduction of tidal flow, these areas may become open water and tidal flats for a century or more before they return to wetland habitat. Different levels of subsidence also result in a wide range of marsh planforms with little or no semblance to the geomorphology of natural systems. The potential use of dredged materials for several aspects of the marsh restoration process — enhancing the sediment budget at low elevations, accelerating the restoration trajectories toward acceptable endpoints, improving the geomorphology of the marsh planform, remediating contaminated areas, providing high marsh elevations for species that depend on this habitat type for survival, reestablishing upland dike elevations for off-site protection of people and property, and stabilizing shorelines to reduce erosion rates — are the subjects of this paper. The abundance of dredged materials from channel deepening projects that will occur nation-wide, the maintenance dredging of major ports, and other projects provide a wealth of opportunities to combine dredging needs with coastal marsh rehabilitation and restoration.

Key words: habitat restoration, coastal marsh

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Use of Ecological Risk Assessment Methods to Evaluate Dredged Material Management Options

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The environmental quality and disposal options for sediments dredged from navigational channels has been judged by use of some combination of physical, chemical, and biological analyses for over 30 years. Early approaches used chemical-specific numerical criteria to evaluate each chemical or class of chemicals found in sediment. This approach has often been criticized as either overly conservative or providing insufficient environmental protection, because several site-specific geochemical and biological factors were typically excluded from the decision-making process. Consequently, an "effects-based" approach, which weighs the preponderance of evidence derived from biological, physical, and chemical assessments, has been increasingly used in the United States to evaluate sediment management options.

The current state of the science in ecological risk assessment is predicated on the use of a weight of evidence approach similar to that used in effects-based sediment toxicity testing. In fact, sediment toxicity testing and ecological risk assessment have been described as complimentary components of a sediment assessment framework. By consideration of both benthic toxicity and bioaccumulation potential in aquatic food webs, the volume and associated costs for dredging and disposal of sediment can be properly quantified and managed. However, several sediment assessment methodologies have evolved in the United States and elsewhere using a variety of approaches with wide ranges of scientific uncertainty and predictability. This paper reviews the useful elements and the limitations associated with the application of a sediment toxicity testing and ecological risk assessment framework to characterize and evaluate the potential hazards of sediment-bound chemicals on aquatic biota and identify disposal options. Examples of sediment assessments conducted in the United States,

Australia, and Western Europe are used to demonstrate the key advantages and limitations.

Key words: ecological risk assessment, sediment assessment

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Contaminated Sediment Management Options in San Francisco Bay, California

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To date, few contaminated sediment cleanups have been completed in San Francisco Bay, California and remediation approaches have been limited to dredging and upland disposal either near the dredge site or at permitted landfills. Dredge and fill projects must be approved by the Bay Conservation and Development Commission (BCDC), a local agency with a legislative mandate to minimize fill in the Bay. Sediment capping proposals have not been approved by BCDC, and nearshore confined disposal and contained aquatic disposal have not been implemented in the Bay. Although beneficial reuse (wetlands creation) projects have been initiated, a long lead time is required because of the complex and lengthy permitting process and active public participation in project development. Additionally, wetlands creation projects have limitations on the quality of material that they can accept. Given these constraints, cost effective remedies for sediments are not always available. Future cleanup is expected at a number of sites around the Bay. The San Francisco Bay area would

benefit from a regional initiative to develop contaminated sediment management options for these sites.

Key words: remediation, contaminated sediment, disposal, wetlands creation, San Francisco Bay, CA

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Restoration of Norton Basin and Little Bay: Beneficial Use of Dredged Materials in Jamaica Bay, New York

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The goal of the Norton Basin/Little Bay Project is to demonstrate the efficacy of habitat restoration of Norton Basin, in Jamaica Bay, Far Rockaway, NY, by filling two borrow pits (55 and 64 ft deep respectively) located at the southern end of the basin using dredged material to a general depth of approximately 15 ft mean low water (MLW).

Preliminary biological and hydrographic sampling in the Norton Basin borrow pit, conducted by the U.S. Army Corps of Engineers (USACE), New York District, in 1998 and 1999 indicated severely degraded conditions. Side slopes in both pits are nearly vertical, and hydrodynamic isolation has apparently resulted in low mixing rates among the deeper layers of water. Preliminary benthic grab and sediment profile imagery (SPI) samples indicate an impoverished benthic community. Basin sediments are highly aqueous/organic and black in color, with no discernable redox discontinuity layer (RPD). Additional indicators of degraded sediments are a high gas void content in SPI samples, a strong odor of hydrogen sulfide, and the seasonal presence of sulfur bacteria mats.

Preliminary trawl and fisheries hydro-acoustics data

indicate little utilization of borrow pits by fish. The few fish that apparently do use them are presumably small schooling forage species (e.g. bay anchovies, Atlantic silversides) that do not rely on the structure of the pits as essential habitat.

Norton Basin and Little Bay are among the deepest locations in Jamaica Bay, including all other pits, and scoured channels. Both basins are isolated from Jamaica Bay proper by a sill at the entrance channel to Norton Basin. The steep configuration of the pit walls is ideal for the placement of dredged material. Filling the pits to return them to more historic depths could dramatically improve hydrodynamic exchange rates, which would improve sediment quality and benthic habitats.

Key words: beneficial use, Jamaica Bay, NY, habitat restoration

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The Experience of Tidal Wetland Restoration Using Dredged Materials in San Francisco Bay – Its Implications for Future Restoration Planning

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Over the last 150 years the San Francisco Bay Estuary has lost approximately 95% of its 200,000 ha of intertidal marshes primarily by diking and conversion to agricultural uses. This loss of habitat has resulted in the decline of important ecosystem functions and populations of listed species. Over the last three decades government agencies and non-profits have embarked on a program to restore tidal wetland habitat. There are now active plans to restore more than 15,000 ha of diked former tidal marshes at various locations throughout the estuary. Almost all of these sites have subsided between 0.5 and 4 meters and therefore will rely either on relatively slow rates of estuarine sedimentation or on filling with dredged material to evolve into vegetated tidal marshes once tidal action is reintroduced.

The 28-year restoration history within the estuary

has provided a valuable learning curve that can guide the planning of large-scale restoration projects now being considered. The first restoration projects implemented in the 1970's were on diked sites that had been used for dredged material disposal. Unfortunately, it was not until the late 1980's that systematic monitoring started to be carried out to determine how these sites had evolved. Based on this information design parameters were developed for the first 'second generation' restoration project using dredged material – the 120 ha Sonoma Baylands project implemented in 1996. In this project ecosystem restoration objectives dictated amounts and placement of dredged material rather than disposal requirements. The US Army Corps of Engineers is now funding monitoring of Sonoma Baylands that will guide 'third generation' designs such as now being planned at the 1100 ha Hamilton Air Force base restoration site.

The feasibility analysis for the Hamilton project provides a practical example of the benefits of using dredged material in tidal wetland restoration. In comparison to an alternative design that relied only on natural sedimentation the dredged material alternative was selected because of the desire to accelerate the evolution to vegetated marsh, and concerns over potential wind wave erosion, scouring of large tidal channels and opportunities to create a gradient of habitat types around the perimeter of the site.

A further factor that will be influencing decisions on whether to use dredged materials on large restoration sites in San Francisco Bay is the potential impact of large-scale restoration on the sediment budget and sediment dynamics of San Francisco Bay. For example the sediment sink created by simultaneously restoring 15,000 ha of subsided, diked former marshes to tidal action is one to two orders of magnitude larger than average annual sediment inputs to the estuary. As the estuary becomes sediment limited it is likely that our perception of the use of dredged material for wetland creation will shift from it being a valuable – to an essential resource.

Key words: wetlands, tidal habitats, beneficial use, San Francisco Bay, CA, habitat restoration

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Contaminated Sediments in the Great Lakes

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Contaminated sediments in the Great Lakes are a long-standing problem with major impacts on dredging and water commerce. Many rivers and harbors in the region are not dredged for long periods of time due to the lack of disposal areas to contain contaminated sediments and uncertainty regarding the location and extent of contamination. This paper will discuss a potential solution for the Ashtabula River in Ashtabula, Ohio.

Focused sampling was completed on locations in the river where data gaps were identified from previous sampling activities. The main purpose of this effort was to more clearly define the areas of the river where Polychlorinated Biphenyl (PCB) levels in the sediment exceed 50 mg/kg. Sediments with this level of contamination are subject to regulation under the Toxic Substances Control Act (TSCA), which mandates specific requirements for handling and disposal of the dredged material. These requirements add significant costs to the project and can reduce the economic viability of removing and disposing of the sediments.

The results of the sampling event were used to create a three dimensional model, using the Department of Defense's Groundwater Modeling System (GMS), representing the PCB contamination in the river. This innovative approach resulted in an almost 50% reduction in the volume of sediments considered regulated under TSCA, as compared with previous estimates, and will result in significant cost savings.

The model was also used to develop alternative dredging scenarios that attempt to maximize the mass of PCBs removed while minimizing the volume of sediment removed and the post-dredging surface area weighted PCB concentration. This approach helped define an alternative dredging plan, accepted by regulatory agencies and the community, that has the potential for further reducing the costs of the project by at least \$16 million.

Key words: PCBs, Great Lakes, modeling

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Design Planning for Salt Marshes Created from Dredged Materials: A Case Study in Galveston Bay, Texas

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Very little information is available on design criteria of salt marshes created with dredge material. Ideally, a created marsh should replicate the variety of environmental conditions and topographic features that allow natural processes and functions to occur. Developing design criteria to insure that constructed marshes will be ecologically functional is a challenge. Our case study in Galveston Bay incorporates measurement of animal utilization in natural marshes and mapping of geomorphology and topography to provide useful information for design ecologically functional created marshes.

Our approach was to quantify and compare nekton densities among vegetated (edge *Spartina alterniflora*, inner *Spartina alterniflora*, *Scirpus maritimus*, *Juncus roemerianus*, and *Spartina patens* marsh) and shallow nonvegetated (pond, channel, cove and bare intertidal) habitat types in selected marshes of Galveston Bay. We collected 267 nekton samples using a 1-m² sampler during two seasons of known high nekton abundance. We also surveyed and mapped major habitat types in each marsh system.

Within vegetated habitat types, two factors, elevation and proximity to open water, were most important in influencing the distribution of nekton. Outer marsh consisting of *Spartina alterniflora* or *Scirpus maritimus* was used most by brown shrimp, blue crab, and daggerblade grass shrimp. Gulf killifish and sheepshead minnow were most abundant within inner *S. alterniflora* marsh or *S. patens* marsh. White shrimp and striped mullet used both the outer and inner marsh. Nonvegetated habitat types adjacent to marsh were predominantly used by gulf menhaden and bay anchovy (marsh channels), spot (marsh ponds), blackcheek tonguefish and Atlantic croaker (coves). Overall, the vegetated and nonvegetated habitat types within, and contiguous with, the marsh system contained higher densities of most nekton than did the nearby shallow bay.

Because nekton-habitat associations are species specific, constructing a variety of habitat types in a marsh

will improve biodiversity. Based on our results, we recommend that created marshes be designed with the variety of vegetated and non-vegetated habitat types that occur in natural marshes. We also recommend that design criteria provide for large areas of low marsh interspersed with numerous channels and interconnected ponds to maximize habitat for fishery species.

Key words: salt marsh creation, habitat, Galveston Bay, TX

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CHAPTER 8

Workshops

SEDIMENT TOXICITY RISK ASSESSMENT: WHERE ARE WE AND WHERE SHOULD WE BE GOING?

Chair person: Michael P. Weinstein

<http://www.njmssc.org/>

SUMMARY

By the middle of this century, global trade is expected to triple, with 90% of the weight and 80% of the value of all international goods transported by water (National Ocean Conference 1998¹). To ship these goods, larger vessels will be required, in turn, requiring expanded ports and deeper navigational channels, some of the latter exceeding 45 ft (15 m) in depth. Nationwide, construction and maintenance of these channels requires the dredging of more than 400×10^6 yds³ (305×10^6 m³) annually, with the volume projected to increase in many areas. The Port of New York and New Jersey is no exception. The Port boasts over 250 miles (400 km) of engineered waterways, requiring $2\text{--}4 \times 10^6$ yds³ ($1.5\text{--}3.0 \times 10^6$ m³) of annual maintenance dredging. Planned channel deepening to accommodate traffic projections will require the additional dredging of over 50×10^6 yds³ (38×10^6 m³) of sediment over the next 10–15 years. These water highways are essential for sustained economic growth; *e.g.*, the Port of NY and NJ now adds over \$30 billion annually to the region's economy and creates hundreds of thousands of direct and indirect jobs.

Unfortunately, sediments that settle into shipping channels also become sinks for pollutants. Contaminant discharges result in the accumulation of heavy metals and persistent organic compounds in the fine sediments of harbors and waterways. Petroleum hydrocarbons and their derivatives, polychlorinated biphenyls (PCBs), dioxins and furans, pesticides, mercury, lead, and chromium, among others are often found at elevated

concentrations in the harbor bottom. Since 1972, the US Environmental Protection Agency and the US Army Corps of Engineers have required that dredged material be tested for potential toxicity prior to disposal at open ocean sites. Recent improvements in the assessment of dredged materials proposed for ocean disposal and increased public awareness and sensitivity to the issue of contamination has resulted in a dramatic decrease in open ocean disposal and placement of dredged materials in either confined disposal facilities, or after decontamination, incorporated as feedstock into varied "beneficial uses". However all of these processes remain significantly more expensive than conventional disposal and threaten the continued economic viability of many ports.

What remains unknown, however, are the true ecological risks and other costs/benefits associated with decisions to dispose of dredged materials, whether in the ocean or upland. As the science of ecological risk assessment improves, decision-makers will ultimately have better tools to address the management of dredged materials. It was the purpose of this Workshop — Sediment Toxicity Risk Assessment: Where Are We and Where Are We Going? — to review the status of ecological risk assessment and discuss what scientists mean when they say, "these muds are toxic", and the corollary, "what is worrisome about dredged materials?" An expert panel was convened on the last day of the Conference, and a series of "challenge" questions posed that were intended to focus the discussion and meet the goals of the workshop. Panel members included: Bruce Brownawell, SUNY, Stony Brook; Dominic M. Ditoro, Manhattan College; Kay T. Ho and Wayne R. Munns, Jr., U.S. Environmental Protection Agency; Peter M. Chapman, EVS Environment Consultants; and Keith Solomon, University of Guelph. Ms. Elizabeth "Bitsy" Waters moderated the session.

To address the issue of sediment toxicity, the New Jersey Marine Sciences Consortium (NJMSC) through its New Jersey Sea Grant College Program and New Jersey Maritime Resources cohosted this session at the Conference on Dredged Material Management, Massachusetts Institute of Technology, Cambridge, MA, on 3–6 Dec 2000. Five invited papers and an edited transcript of the facilitated Workshop appear in a New Jersey Sea Grant publication.² This summary is adapted from

¹National Ocean Conference - Oceans of Commerce, Oceans of Life; June 11–12, 1998, Naval Postgraduate School, Monterey, CA.

²New Jersey Sea Grant Program, "Proceedings: Sediment Toxicity and Risk Assessment: Where are we and where should we be going?", NJSJG-02-482.

the preface to that report. The five papers also appeared separately in *Marine Pollution Bulletin*.³ One of these papers — Issues in Sediment Toxicity and Ecological Risk Assessment — is a synthesis article prepared by the workshop panel from the morning discussion. A series of “challenge” questions guided the discussion, and care was taken to constrain the topic to ecological risk assessment and refrain from introducing human health concerns into the dialogue:

Research/Technical

1. How Do *Scientists* Define Sediment Toxicity?
2. How Do We Establish Baselines for Toxicity (Reference/Background)?
3. How Do We Select Appropriate End-Points (e.g., SQC or Bioassays; Tiered Approach or Integrated-SQC)?
4. How Do We Evaluate Ecological Significance of Endpoints or Bioassays?
5. How Can the Magnitude of Uncertainty Be Quantified, Reduced, and/or Managed?

Science-Based Management/Policy

6. What Type of Information Does a Manager Need from the Scientific Community?
7. What Type of Information Does the Scientific Community Need From Managers?

Regulatory Decisions

8. Can Sediment Toxicity Measurements be Applied Nation-Wide?

Michael P. Weinstein
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³*Marine Pollution Bulletin*, Vol. 44, Issue 4, April 2002, Elsevier Science Ltd.

NOAA-SEA GRANT ECOSYSTEMS AND HABITATS SYMPOSIUM ON THE BENEFICIAL USES OF DREDGED MATERIALS FOR WETLANDS RESTORATION

Chair person: Barry A. Costa-Pierce

<http://www.uri.edu/cels/favs/bcp.html>

SUMMARY

A second workshop was convened on Beneficial Uses of Dredged Materials for Wetlands Restoration. This summary represents a consensus of workshop participants and is reprinted from Appendix A of a recent issue of *Ecological Engineering*.¹

America's coastal ecosystems provide communities with shelter from dangerous storms, purify the Nation's waters, and sustain coastal economies with billions of dollars in fisheries, tourism, transportation, and recreational income. However, in many states dramatic population growth and development are increasing habitat loss and the degradation of water quality, which threaten coastal economies.

Three National Research Council (NRC) studies addressing these issues have concluded that the restoration of coastal ecosystems should be a national priority. One NRC study stated "Federal science agencies should encourage rapid advancement of the science and engineering of ecosystem restoration and rehabilitation." The Clean Water Action Plan, the Coastal Wetlands Protection, Planning and Restoration Act, the Estuaries and Clean Waters Act, and the Beaches Environmental Assessment and Coastal Health Act provide the needed legislative framework to accelerate the restoration of coastal ecosystems.

A ready means to facilitating coastal habitat restoration lies in the maintenance and expansion of the Nation's ports. More than 200,000 cubic

meters of uncontaminated coastal sediments are dredged each year for port maintenance and related activities and are discharged into the nation's waters or deposited at land-based facilities. The current practice of disposal of uncontaminated dredged materials into America's coastal waters and landfills creates a needless waste of the Nation's ecological, engineering, economic, and scientific resources. Many dredged material containment facilities are nearing capacity-or are already full-and opening new containment sites or disposal facilities creates social and economic conflicts. Uncontaminated dredged materials are potentially valuable resources for habitat creation, restoring wetlands and beaches, or as construction materials. Methods for discerning which dredged materials can be used for habitat development and restoration-since not all dredged materials are suitable-are relatively straightforward, or are in rapid development.

In this respect, we recommend that the United States Army Corps of Engineers join with NOAA to lead an interagency effort to address the following priorities:

- Inventory and prioritize the restoration potential for coastal and riparian ecosystems in the Nation and maintain a central data center for coastal restoration projects using uncontaminated dredged materials,
- Understand the engineering practices and ecological fidelity needed to create "functional" coastal ecosystems, with special emphasis on understanding essential habitat features and biological interactions that support ecological functions of restored coastal and riparian wetlands,
- Identify those situations where dredged materials are NOT appropriate for habitat restoration, due to such factors as sediment porosity, erosion potential, contaminants, etc.,
- Understand issues of scale and transferability of models, the proper roles of reference sites, and the applicability of small-scale experiments to ecosystem and landscape-scale restoration practices,
- Develop interdisciplinary teams of scientists and engineers tasked with conducting long-term research and monitoring to guide successful restoration practices,
- Coordinate activities among scientists, engineers

¹Reprinted from *Ecological Engineering*, Vol. 19:3, Costa-Pierce and Weinstein, Use of Dredged Materials for Coastal Restoration, pages 184-186, Copyright 2002, with permission from Elsevier.

and practitioners to forge agreements on objectives and performance standards, accountability in the restoration process, adaptive management practices ~ and the use of current scientific information in informed decision-making,

- Support research efforts to develop new technologies to clean contaminated sediments and to minimize the impact of handling sediments of all types, and
- Develop innovative university curricula and standards for training a new generation of ecological engineers specializing in coastal restoration projects.

We the undersigned attest that this consensus statement represents a fair and accurate summary of the presentations, discussions and recommendations from the NOAA-Sea Grant Ecosystems & Habitats Workshop on Beneficial Use of Dredged Materials for Wetlands Restoration. We recognize that there has been an inconsistent past performance in the beneficial uses of uncontaminated dredged materials for habitat creation and ecosystems restoration.

Consequently, we endorse the need to better understand and overcome past constraints and to accelerate the beneficial uses of uncontaminated dredged materials in order to dramatically reduce the need for disposal. We urge the United States government and its agencies to adopt policies to use every cubic meter of uncontaminated dredge materials for the restoration of degraded coastal ecosystems-when such use is shown to be cost effective-to improve the coastal economy and environment of the United States.

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THE USE OF CONFINED AQUATIC DISPOSAL (CAD) CELLS TO MANAGE CONTAMINATED SEDIMENTS IN PORTS AND HARBORS

Co-chairs: E. Eric Adams and Judith Pederson
<http://web.mit.edu/seagrant/>

SUMMARY

Options for disposal of contaminated sediment are limited by public perception, regulations, technical uncertainties and cost. The disposal option selected for the Boston Harbor Navigation Improvement Project (BHNIP) was confined aquatic disposal (CAD) cells—constructed in-channel, filled with contaminated sediments dredged from nearby, and capped with clean sand. Although CAD cells have been used for over 25 years, there are surprisingly few scientific and technical studies that examine the processes involved with disposal, consolidation, capping and recolonization. This workshop provided an overview of some of the processes with an eye toward assessment and effective management of CAD cells.

Unlike the other two workshops described in this volume, the CAD workshop focused on audience participation structured around topics that were introduced by group leaders. The topics, and their group leaders, included:

- Overview of CAD Cells (Thomas Fredette, US Army Corps of Engineers)
- Physical/Geotechnical Processes (Ole Madsen, Sanjay Pahuja and Eric Adams, MIT)
- Chemical Migration (James Shine, Harvard School of Public Health and Philip Gschwend, MIT)
- Biological Impacts and Response (Judith Pederson, MITSG)
- Project Proponent/Regulator Interactions Issues (Deborah Hadden, Massport; Susan Nilson, CLE Engineering; Steve Wolf, ENSR, and Deerin Babb-Brott, MA Coastal Zone Management)

An edited transcript of the workshop follows.

OVERVIEW OF CAD CELLS

**Thomas Fredette, Director of DAMOS, US
Army Corps of Engineers, NED**

Tom Fredette provided an historical perspective on the use of CAD cells and answered a set of rhetorical questions intended to provoke subsequent discussion.

Confined aquatic disposal (CAD) cells are depressions in the bottom sediment that are either natural, or intentionally created as in the case of Boston Harbor. CAD cells are designed to sequester materials by placing sediment within the cells and, for greater isolation, capping them. In so doing, the surface area initially covered by the material prior to placement is minimized, and thus there is less exposure.

Perhaps the earliest CAD cell was constructed in Norwalk Harbor, CT, where an evacuated pit near the I-95 bridge was filled with 2000 cubic yards (cy) of sediment contaminated from a nitrobenzene spill. Materials were mounded on the bottom of Long Island Sound and capped.

There are several issues raised in the use of cells relating to physical, chemical, and biological processes, management, and policy. These have been highlighted under each general category. *The questions and answers reflect Tom Fredette's perspective and should be examined in light of later discussions.*

Physical Processes

How does the long-term life of CAD cells compare to other options? In general CAD cells are stable and compare favorably to other options.

Is material surge from cells an issue? In general material placed in a cell remains within the cell; however, there are times when material spills onto the surface outside the cell. This is a concern that can be addressed by monitoring and taking necessary actions to clean up the material that is outside the CAD cell.

Is bulking an issue in designing CAD cells? Bulking is not a significant problem. In typical dredging projects, material is taken from a relatively

large area where it is spread out and put into a situation where it has a tremendous overburden. Over the length of the project these things are going to balance out so you may not need to plan for much bulking.

How do we know when to cap? There is no existing engineering guidance on when to cap sediments in CAD cells. Follow-up questions are, when has the material reached a sufficient strength and how do we measure that? Although these are interesting scientific and technical questions, I do not consider these issues important in the overall disposal of sediments in CAD cells.

How do we increase material strength? There may be circumstances when it is necessary to increase the ability of material to support a cap. A relatively simple solution is to do so during the pre-capping phase, *e.g.* pre-load the sediments with some material and come back later to cap once the strength desired is reached.

Are plumes a problem when the material is being placed in the cell? Generally no. The U.S. Army Corps of Engineers (USACE) has developed the STFATE models that are extremely conservative and these models do not predict that the plumes are a problem.

Are currents from vessels an issue? This is an issue that should be considered when designing the placement of CAD cells. For CAD cells placed within a channel, the cells are going to be below the surrounding area and deeper than the surrounding channel. The extra depth of the cells may reduce this to a relatively minor issue.

Are the sites sediment traps? This is an unknown and documenting that this occurs would be useful in terms of management.

Are the cell (pit) walls stable? Pit wall stability is an engineering issue that may require site-specific investigations. The stability of pit walls depends on the sort of side slopes that are used. In Boston Harbor the underlying material, Boston blue clay, was stable and very steep side slopes were dug.

Is chemical expulsion a concern during the consolidation process? Averaged over the life of a CAD cell, the mass of chemicals released, and the rates of release, are going to be relatively small. I very definitely do not consider this an important issue.

Chemical Processes

Is groundwater transport an issue? This is not likely, but may be on a site-specific basis. Often materials put into these cells have very low permeabilities, perhaps less than the material out of which the cell was dug, so they may not conduct water very well.

Is gas production within the cells and its transport to the surface a potential vector for contaminants, particularly organic pollutants? This is an unknown, but mass and rate are likely to be very small.

Do we need to cap? Capping is probably not necessary in many instances. Usually it will be very difficult to bring cells up to the existing bottom level. By and large the CAD cells will be below the sea floor and they will function as bottom traps so capping will do very little in these cases. However, as noted earlier in Long Island Sound, the material was mounded and capped. This may be a site-specific issue.

Biological Processes

Is bioturbation a concern? There is a need to plan for it in consideration of the organisms that are known (or are likely) to reside in the sediments.

Will dissolved oxygen be depressed? Determination of dissolved oxygen will need site-specific investigations.

Policy Issues

Who bears the liability? Liability is a big question, but the same question should be asked about open water disposal sites or any place that receives waste. Subtidal areas are public trust lands that will dictate who bears the liability.

Is environmental insurance the answer? There is very little information on what environmental insurance covers and who sells it.

How do we fund multi-user sites? The Commonwealth of Massachusetts is struggling with this to some degree right now, as are other places. There is a need to be creative.

Are regulatory changes needed? This is a much-needed area for discussion. Any proposed regulatory changes may vary from state-to-state. Are there federal regulations that also need changing or adjusting?

COMMENT: Your answers are largely applicable to a situation like the one here in Boston Harbor where you have a dirty place to begin with and you are sort of sweeping it all together into a pile and putting it into a hole right there in the same dirty place. We ought to all keep in mind that CAD is an option that is being considered in a lot of different settings, for a wide range of contamination, different from what you would find here (in Boston Harbor). I think that a lot of your answers would not apply to some of these other settings.

PHYSICAL/GEOTECHNICAL PROCESSES

Ole Madsen, Sanjay Pahuja and Eric Adams, Department of Civil and Environmental Engineering, MIT

This section of the workshop examined physical processes involved with dredging, disposal and consolidation activities. The format allowed for several brief presentations followed by questions and answers related to each presentation. This was followed by a general discussion of physical processes that highlighted what is known and future directions.

Sediment Migration

Ole Madsen began by discussing the migration of sediment, which results from the difference in grain size, and hence transportability, between native

sediments surrounding the CAD cell and the material contained in the CAD cell (if there is no cap) or the cap material (if there is a cap).

Sediment migration has relevance for environmental impact and cap design. For example, if there is just a mound of dredged material (no cap), you want to find out how it spreads with time. If there is a cap, you want to know how cap material may migrate from the cell, or how native material may migrate into the cell, so as to design a better cap.

Madsen showed a figure with a tidal flow passing alternately across a silty native bottom to a sandy cap region and vice versa. The abrupt change in bottom grain size implies that the overlying water column has a different capacity to hold suspended sediment. However, it takes time for sediment to diffuse vertically, such that only the water immediately above the bottom is saturated with sediment. After the transition in bottom sediment characteristics, water coming from the relatively fine region will be over-saturated with sediment which will tend to deposit, while water coming from the region of relatively coarse bottom sediment will be under-saturated, and will experience erosion. The time scales for vertical sediment diffusion, coupled with the current speed, will cause bottom sediments to disperse horizontally.

Unfortunately most models do not account for the finite response time, but assume that, as a water column passes a transition in bottom sediment type, it attains an instant equilibrium. As a result, the processes of deposition and erosion are predicted to occur along an unrealistically narrow line perpendicular to the current, at the edge of the CAD cell. If the model is a numerical model, with spatial discretization, these processes are spread out over the width of a grid cell, but the degree of spreading is improperly dictated by the width of the grid cell, rather than the transport of the sediment.

Madsen referred to recently completed research by his student, Sanjay Pahuja, involving development of a dynamic model that more realistically handles transitions in bottom sediment type. In addition to applications to regions of sharp discontinuity in bottom sediment characteristics, this model also applies to regions in which the spatial gradient in

near bottom sediment concentration is caused by spatial gradients in bottom shear stress, as might be found with significant variation in wave height or water depth.

COMMENT: I am interested in any observations on cell size. In Boston we range from very small cells to very large cells. I know there were some issues about spreading capping material out, in terms of loading from the center.

Consolidation Processes

Sanjay Pahuja, a Ph.D. student in Civil and Environmental Engineering, MIT, discussed strength development in recently deposited dredged materials, which relates to the questions of when to cap and how much to cap. This research was done at MIT, with support from MIT Sea Grant and the US Army Corps of Engineers, as part of the Marine Center on the Behavior of Capped Contaminated Sediments.

Pahuja showed two short videos that set the stage for his presentation. Black material shown at the bottom is silt that was collected from Reserved Channel before the dredging started in Boston Harbor. This silt was placed in a small aquarium by depositing it through water, as might have occurred during dredged material disposal. In the first video, twenty-four hours after depositing the silt, sand was gently poured through the water covering the silt, as might have occurred during cap placement. The video showed that much of the sand fell through the deposited silt leaving sections of the silt with no sand on top. The second video depicted the same process except that the sand was placed three days after the silt had deposited. In this case, the sand formed an intact cap.

These videos illustrate, qualitatively, the importance that the undrained shear strength of the underlying material plays in determining the bearing capacity of the dredged material, which in turn will determine how much capping material can be put on top. This process is time dependent.

Research shows that materials gain strength over time, but there is no good way of predicting how this will happen and no theory in the literature. There are almost no experimental methods

for dredged materials. Dredged material is very soft and its strength is very low so all the instruments in geo-technical engineering that are normally used for strength measurements are not reliable (at these low strengths).

Shear strength is a function of a number of parameters. Three of the more important ones are discussed as part of my experimental design: (1) water content, (2) effective stress and (3) age. Two different mechanisms are identified as the main factors in strength development. The first one is consolidation, *i.e.*, the volume change that happens as the water content of the deposited material changes. There is an associated change in strength as consolidation happens. The second process is thixotropy. This is a purely time-dependent process. In thixotropy the water content remains constant, the effective stress remains constant, but with an increase in time, bonding happens in the material and it becomes strong. That is what the video illustrated because we did not see any consolidation happening in one day.

These are reversible processes. If strength is plotted against time, strength increases with time, but if sediment is remolded, mixed, or disturbed, its strength falls; if it sits again strength returns. That is what happens when we are first dredging the material. As sediment is removed it is disturbed and loses its strength. It gains some strength during the time it is sitting in the barges and then again as it is deposited it loses that strength. The cumulative effect of thixotropy and consolidation is what we need to be able to predict and to that end we conducted the experimental program here.

We need to look at strength from different perspectives. There is the issue of surface strength. If there is not enough there, the cap is going to fall down until it meets a layer that can support it. The surface strength is also very important when looking at the erosion of material. For geo-technical stability we want to look at strengths in deeper zones of this material. We need to consider the strength behavior of this material at various depths.

In my experiments I took material from Reserved Channel in Boston Harbor before the start of dredging. We homogenized it and put it into cold storage so it could be used for three years.

In the critical low effective stress regime, which occurs in the top layers of the sediment, we used samples of the sediment that were up to twelve inches high. We wanted to see how the scaling occurs so we examined samples that were 3, 6, and 12 inches high. These samples were prepared at different initial water contents—150, 200, and 250%—to look at the effect of initial dilution. The material in its natural state as placed in a barge is 160%. We looked at different consolidation times, from one hour to thirty days. Our best guess on the coefficient of consolidation for dredged material showed, with a preliminary calculation, that a 12-inch sample would be consolidated by the end of thirty days. Later we found that that was not true because we did not have a good estimate of the coefficient of consolidation in the low effective stress range. That points to another problem: we need a get a good handle on consolidation properties of these materials under low effective stresses, which are not easily available.

Spurred by an audience question, Pahuja described MIT's automated fall cone developed to measure low shear stress accurately.

To examine intermediate effective stress, which would occur at deeper sediment depths, we simulated depth by placing a load on top of the material. We also changed the boundary conditions to double drainage, which reduces the length of the experiment. We built up loads starting from 6 grams and used a load increment ratio of one (*i.e.*, doubled the load at each step). Conditions of up to 10 feet of depth can be simulated in this manner. Once the sample was consolidated to the desired level of surcharge we performed strength and water content measurements. The depth profile is not important because the amount of surcharge we are putting on is far more dominant. We can get measurements of both strength and water content in the intermediate effective stress range that takes me up to ten feet of depth. After that I can use classical geo-technical laboratory equipment and the constant rate of strain test (CRS) to extrapolate to 100, 200, 300 feet of depth.

Data were presented showing the relationship between water content and effective stress. In high

effective stress zones the effect of initial water content is diminishing, whereas in low effective stress regimes the virgin compression curve is branching out. This is the first study of this effect in the low effective strength zone.

Additional data were presented showing shear strength versus effective stress. We start from a shear strength of 0.45 g/cm² which is the remolded shear strength. As the material starts consolidating shear strength increases. We still do not know to what extent this is happening because of consolidation and to what extent it is due to thixotropy because they are both happening at the same time.

We want to have a predictive capability. How do we do that? Let us examine the graph of measured void ratio and shear strength versus effective stress curve. If I assume that all of the profiles ultimately converge to a unique consolidated profile, I can extrapolate the behavior down to low values of effective stress. I can then find the effective stress corresponding to the extrapolated values of void ratio and use that value of effective stress to plot shear strength. (*This was illustrated with a slide.*) There are error bars that could be significant, but at least it provides a good methodology: it tells us what we would have to do if we go to a different site where we have a different material. It will also show us what the important factors are; initial water content could be an important factor for a different material. That is where this experimental research is very relevant to a capping project. With that I conclude and I am open to your questions.

QUESTION: I thought it would be relevant to discuss some things we found in the field during the Boston Project. For one thing, we observed that water content did not vary much from *in situ* (in the harbor), to in the barge, to in the cell at the beginning, to in the cell after two months, to under conditions of a cap. Part of the problem is that this sediment is so heterogeneous that numbers are all over the place, so it is hard to get a statistical value. All of the laboratory data and all the theoretical models predict that capping should not work and yet it seems to have.

RESPONSE: With this effort we are suggesting that we use widely available consolidation models

to get an idea of what the effective stresses are in a CAD cell after a certain time following deposition. That then gives us a correlation between effective stress and shear strength. On top of that we add the thixotropic component because we believe that proceeds on its own lines if you are not disturbing the cell. We are finding that when you increase the effective stress, the thixotropic component accelerates, so we do find a reason why applying a surcharge before capping, or using incremental capping, actually makes the cap more effective—it is because of the accelerated strength gain under a load.

QUESTION: You have come up with a method to measure shear strength under very low effective stresses, but my question relates to what you do with that data. I can go to a solid mechanics textbook and find an equation that I can use to design for the bearing capacity of a structure pressing down on a foundation. Those are the only bearing capacity equations I know about and here we have got a pit that is almost a liquid material and if we can place a cap all the way across it we have got it confined and I do not believe those bearing capacity equations apply to that case. My question is, what do we do with the shear strength data? What equation can we go to?

COMMENT: Where is the equation? You are always asking where the equation is. This is one aspect of CAD design I do not think we have an equation for.

QUESTION: So I guess my question to you is are we going to try to look at that through this work or is this still a different path that needs to be looked at. To me that is the crux of the matter. You have done good work to get us the shear strength number but that is a parameter, not the design.

RESPONSE: A couple of years ago I found a paper where the authors had equations to estimate bearing capacity if you had an infinitesimally long linear strip loading which is what I would think would happen if you disposed of material through a split hull. I really have not looked farther than that.

QUESTION: What I am getting at is that all of

those equations, whether they are for a square footing or a round footing or anything, they are all applying here and it is essentially a slope failure equation really so when you have an situation that is different than that, there is no edge effect. All those equations are based on failure at the edge of a failure plain and we do not have that with a CAD cell.

RESPONSE: No I completely agree. That is one area that is very open and needs more research.

COMMENT: I think you could in fact look at it a little bit like plasticity. The bigger problem that I see is how do we place sand in a nicely layered way.

COMMENT: It comes back to writing specifications for a contractor, where you prefer not to specify the method of placement, but rather a level of performance for the cap. Contractors are all going to have different equipment and their equipment is fairly crude. In the laboratory or in small pilot tests we can do all sorts of nifty things in terms of strengthening sand but an 8,000 cubic yard scow—that is a blunt instrument.

COMMENT: Another point to make is that when you have very low shear stress at the surface we cannot hope to ever lay down a sand cap of really soft material with a completely clean interface. There is always going to be some depth of mixing that you need to account for when you come up with the total cap thickness. The data that you are developing here may lead us to eventually predict how thick that mixed layer is going to be. If you are really interested in issues like chemical migration you must factor that the layer where you have cap material and contaminated materials mixed together into the estimation.

COMMENT: I gave a talk yesterday but I wanted to just take a few minutes to give my feeling and views on what we have been talking about. I am not a civil engineer by training. I come to this through solid mechanics and ocean engineering and so I have a slightly different view on these things. What I am working on is knowing when to cap and pre-capping. This all depends on consoli-

dation. We have a free-fall cone penetrometer that you drop down, it hits the fill and you can measure the undrained shear strength and the pore pressure.

Just from my tests looking at this, this is what I see. You put this fill in a box and above it you have a Newtonian liquid. Then you have some turbidity; it is no longer a Newtonian liquid, and it behaves strangely. Then when you get down to the pit where it has been sitting for some time and consolidating under its own weight, you actually get to sediment or a soil. You do have this middle region that does not behave like what you see in soil mechanics textbooks so if you are talking about bearing capacity or putting a foundation on it, its just not going to work. Additionally it is in a box, and you are going to have edge effects from this box.

In our computer models if you have a perfectly flat cap with a small hump in the middle you are going to get failure planes. It is possible that if you move the hump over to the side and have non-symmetrical failure planes, the cap is going to start tilting and fall into the fill. But if you look at the side-scan sonar data the caps are all really bumpy, there are waves and patchy areas but it all seems to be sitting on top and we are not sure why that is. It seems to us that it all should be just falling into the till. So those are issues that I am grappling with. What I am trying to do with this cone penetrometer is to be able to look through the water column, through this "viscous goo" into the consolidated fill and measure how the shear stress and the pore pressure evolve over time.

I am looking for a place to do this and for people who are willing to support such an effort. All of these questions about bearing capacity that we have discussed, they do not seem to work because we are not putting a foundation on a soil, we are trying to put a big pile of sand on some "squishy stuff" and it is a completely different situation. I hope that from my experiments we might be able to get a better idea of how this (shear stress and pore pressure) is changing with time.

QUESTION: Could you go over the logistical constraints of actually using that instrument over a cell? Could you damp out the oscillation that you might have if you are on a free-floating platform? Does it have to be rigidly fixed? Are those things

you can correct for?

RESPONSE: It is free-fall. It is four and a half inches in diameter and it is specifically made for working in softer sediments. That is why it has the large diameter. It is a piece of pipe with a pointy end. You tie a rope on the back and just drop it. So it is not connected to the boat in any way. It just falls through the column, hits the bottom, and starts recording the dynamic penetration resistance.

QUESTION: How are the data recorded and transmitted?

RESPONSE: Currently there are a couple of ways you can do it. You can start it logging. So you drop it and it records at 500 Hz. That way you get 500 samples per second as it hits the bottom. You pull it back up and drop it again and just keep doing that. I think that you can do it about 20 times. Then you just plug your PC onto it and download the data. Or you can do it one at a time and download after each drop. We are working on being able to do this in almost real-time.

QUESTION: Have you done any tests to determine what kind of penetration you get?

RESPONSE: The people who make this and use it have gotten more than a meter in really soft sediments. If you have sand, that changes things. You can weight it. If you have a thick sand cap and you want to punch through it, it would be more efficient to have a thinner probe with a lot of weight, rather than a fat one.

QUESTION: Could not you use a conventional cone in those instances?

RESPONSE: Part of the reasoning behind this is that it is faster, cheaper and you can just follow along a survey line dropping this thing, pulling it back up, dropping it again. It takes literally 30 seconds to run the test and then you can pull it back up and move along. It is a lot faster than driving a cone down. With the conventional cones you often get no record in the upper five feet or so. What I found when I was looking at this was that some operators will actually push the cone down in

initially and that is holding the barge in place. So you cannot really get that initial data because they have to push it in first to anchor their vessel. That is not really useful for us.

Open Discussion on Physical Processes

Eric Adams led further discussion aimed at answering Tom Fredette's questions.

Maybe we can return to Tom's slides and his various bullets to see whether we can agree or disagree with his original assessments. What are critical issues that we need to address? Where are the gaps?

How long-term are CAD cells?

COMMENT: I think this is an issue. I am from the Puget Sound area and recently we had some negative press because of an incident in a local harbor. A tug operator came in and anchored vessels on top of the cap of a CAD cell. The U.S. Environmental Protection Agency (USEPA) said that they were violating their permits for using the land and now they have to go back in and restore it. I know in Puget Sound long-term reliability and permanence are major issues. In 50 to 100 years when we are all long gone or long retired and someone may come out and do a dredging project on top of a pit CAD—I think this is a legitimate concern. We need to implement reliable institutional controls.

COMMENT: It is worse than that. These sites are owned by the state. In our state the folks who own these sites have taken two positions. One, if you ever build one you have to pay to lease that land which drives cost up past just construction costs. And two, we will never let you build one on our land.

COMMENT: The West Coast may have some special issues regarding long-term stability, *e.g.*, planning for monitoring after storms and earthquakes. This makes it less viable on the West Coast.

COMMENT: How long is long-term? If you are in the nuclear business and you are looking for a

depository you are talking tens of thousands of years.

COMMENT: But keep it in perspective with your other alternatives. How long is long-term for them? Is it similar or not? Getting back to the question of liquefaction if we have this situation sans cap and it liquefies....

COMMENT: In Puget Sound there are differences because we are designing CAD cells up in the bays at elevations of minus thirty but they are within 10s or 100s of feet of bottoms of bays at minus 300 or 400. Large mass-wasting slope failures are known to have occurred.

QUESTION: There is one question that came to mind when Mark was making his comments. Have you looked at or is there any concern about going back into these areas later on with dredges, with spuds and trying to dredge in the area of these cells?

RESPONSE: Yes, that was definitely a concern. These are probably going to be areas where spudding down is going to be difficult. You fill up your whole channel with them and what are you going to come in with next time around?

COMMENT: This question is related to what we are thinking concerning dredging in Gloucester Harbor, Massachusetts. If you lay down a CAD cell that you want to integrate into harbor management or harbor planning and put a mooring field on top of it, how well does the sand cap behave and can you drop concrete block moorings down on top of it? Can you use it as a mooring area and really integrate the CAD cell area into harbor use and not have to set it aside and lose the water sheet on top of it?

Is material surge from CAD cells a big issue?

QUESTION: Is material surge a big issue or can it be handled with monitoring? That is, if we find material lapping over, can we just come back in with a cleanup operation or place a cap on it?

COMMENT: I think that cycles on to the chemistry

issue as well. It depends on the nature of the contaminants.

COMMENT: This also relates to where the CAD cell is located in terms of the ambient sediment quality in relation to the sediments you are putting into it. It is a huge issue if you are exporting material into, for example, outer New Bedford Harbor, Massachusetts from inner New Bedford Harbor. If you are working in Boston Harbor and just moving stuff spatially perhaps it is not as important.

COMMENT: There was some initial thought in Boston that we may have seen some material coming out of some of the cells, but I do not know that we ever had any hard evidence of that. I am not sure if that is an issue or not.

COMMENT: We saw that it was an issue in Puget Sound. We definitely saw material come out of some smaller cells. This goes back to surface area; minimum required surface areas are something that needs to be examined.

COMMENT: Boston Harbor had over-dug cells, with material well below the lip. That was a contractor decision to be conservative.

Do we need to plan for bulking in CAD cells?

COMMENT: It depends on the method of filling. If you fill it hydraulically it could be a very big issue.

COMMENT: Even with hydraulic filling, it is a time factor.

COMMENT: You do not want to underplan. You need a safety factor.

COMMENT: We ran into the reverse problem in the Chelsea River. That pit was excavated anticipating a much larger volume and it is barely half-full. It has been left open for future projects.

Are plumes a problem when the material is being placed in the CAD cell?

Let me make an initial comment based on the

experimental work done by Gordon Ruggaber (*one of the graduate students participating in the Sea Grant Marine Center*) who presented a poster yesterday. The plume effect in a cloud of sinking sediments is really strong. That is, for material that makes it into a particle cloud, the entrainment is very effective: any material that wants to skip out of the fold is pretty quickly sucked back. I think the problem comes if and when material never gets into such a cloud in the first place. We found that, once released, sediment that was submerged and did not have a lot of initial momentum pushing it down, was slow to get out of the chute. Up to one-third of the material never made it into an organized plume. We started with very idealized conditions including a trap-door that immediately opened to try to maximize the amount of material getting into that cloud. (*Shows slide of the experimental "trap-door".*) Material that does not exit immediately does not have a chance to get entrained. And if this occurs in deeper water, stratification and ambient currents can move the material away. I think that is where most of the loss would come. That is the part that is going to get into the environment, from the initial deposition standpoint, and it is probably much more complicated in the real world than in the idealized plumes that we have been studying.

COMMENT: Our observation in Boston Harbor is that the material seems to be pretty well contained, but this may be a depth question. The material is being inserted about twenty feet down into the water column because of the draft of the barge. The insertion point is at twenty feet and the lip is at 40 feet so the process largely occurs below the lip most of the time. I maintain that Short Term Fate (STFATE) is extremely conservative.

COMMENT: Having done some observational work, I am hard-pressed to consider plumes to be a problem. They are short-lived. They are closely confined to these areas. We are not seeing water quality violations. It does not seem to me that it is a major issue.

COMMENT: From the science side that may be the case, but from an outreach or development of public participation and investment and success of

the project perspective, plumes are an extraordinary issue.

COMMENT: I can understand that because I am dealing with a large plume in Mass Bay, but the issue is how do you present that? How can we find better ways to present reality versus perception? Maybe it will never sell, but we do need to find a better way to present these things.

COMMENT: I would like to just add a couple of anecdotes from Boston Harbor. There was not much turbidity in the water column, but if you look below the surface of the cell, the turbidity goes way up, although it is all contained. One of the constraints put on the disposal was that it had to be within a window around high tide to get the most water column and to lessen water current conditions. But high tide is when most of the vessels sail. So you have the contractor trying to squeeze in a disposal right before a vessel would leave and in the end it appeared that a low tide disposal would work just as well. The other issue that I would offer is the benefit of some of the acoustic Doppler techniques. Being able to visualize a plume throughout the whole water column appears to have good promise.

Are currents from vessels an issue?

QUESTION: When this was first in the Environment Impact Report (EIR), there was an initial proposal to armor the cell caps to protect against prop wash from Liquid Natural Gas (LNG) tankers. That dropped off, but were calculations done concerning the ability of the cell to hold the armor cap?

RESPONSE: I think there was some work done on that. I do not know how much. In association with the vessel passage work we did, USACE Waterways Experiment Station (WES) is planning to do some of those calculations. I think the most critical thing is that by and large these large vessels are not moving under their own power very much.

COMMENT: But the vessels that are moving them probably have greater scour velocities. In Puget Sound the most powerful tugboats, those with

highest horsepower, are cycloidal propulsion systems, which have a large thrust component directly downward when they move, and there are no models for prop scour with cycloidal or other non-traditional propulsion systems. It is not the big vessels in the harbors. At best they are turning the screws just to keep their engines going.

COMMENT: I would agree. Probably a greater issue with the big vessels was not the screws but the displacement. When they go by they displace a lot of water and then it rushes back in behind them.

COMMENT: It is very much a siting question and knowing the vessels is important. Tugs are a problem because they put out a lot of horsepower.

COMMENT: This topic is a candidate for a lot of study. We need to talk to the people who are designing vessels and tugs and figure out how their propulsion systems move the water under the vessel.

COMMENT: When we were playing around with that issue, I think it was John Roberge at OCC who did some of the work. We were trying to get a handle on it and the only things we could find—and this was very crude—were a couple of papers from the UK on hydraulic harvesting of shellfish. They were reverse thrusting and blowing the stuff around. A couple of papers were presented talking about forces and impacts and depths of scour.

COMMENT: There are some models that look at this. Steve Maynard at WES is the specialist on this. He has done a lot of work on scour from prop wash. He has developed several different types of equations to examine this once the characteristics of the vessel are known. Some of the equations might not be applicable to the types of configurations you guys have been talking about, but there are people who do this kind of work and we have some tools available.

Are CAD cells sediment traps?

QUESTION: Are there any observations from the West Coast, any monitoring there of cells that are depressed below the harbor bottom, in terms of

some sediment-trap kind of data?

RESPONSE: The fisheries people, at least in Washington, will not allow a permit for any kind of depression in the bottom that does not allow daylight to reach the harbor bottom because they are worried about dissolved oxygen depressions and fish mortality.

COMMENT: If CADs are sediment traps, is there a way to think about putting them where they become interceptor traps that reduce the dredging cycle? Then you have a focused area where you can go in and dig out.

COMMENT: I suspect the ones in Boston are going to provide a lot of advance maintenance.

CHEMICAL MIGRATION

James Shine, Harvard School of Public Health, Harvard University and Phil Gschwend, Department of Civil and Environmental Engineering, MIT

Jim Shine began with an overview of processes that affect chemical migration.

We think of sediments as a sink for contaminants—that is one reason that we need to dredge them, because they are exerting adverse ecological effects. They can also be a source of contaminants. You can think of the water and sediments as being in equilibrium. If we put our efforts into reducing sources to, say, Boston Harbor we may find that to reestablish that equilibrium, substances will be coming back out of the sediments into the water. Again that is one of the motivations for dredging sediments. One is to remove toxic sediments. A second is so we can insure that we will see improvement in the ecosystem as a whole.

What I want to talk about is how the contaminants move in the sediments. How do they move between the sediment and the water? What are the basic processes and how might these processes be altered or how might we have to consider some of these processes when we cap the sediments? *He*

shows a definition slide summarizing basic transport processes.

First I will talk about sediment-water fluxes of contaminants. One of the main processes is diffusion. We have a diffusion gradient between pore waters in the sediment and the overlying water, so we will see a flux out of the sediment into the water. These fluxes can be rather large. They are one of the main sources of metals into the surface waters of Boston Harbor. I did a study in New Bedford Harbor where I was able to show that tens of thousands of kilograms per year of metals are coming from the sediments into the overlying waters. Indeed, the sediments were one of the main sources of metals. What is maintaining this diffusion gradient, and actually can maintain it for a long time, is the combination of the bioturbation rate and the sedimentation rate. Bioturbation—organisms mixing up the top few centimeters, or sometimes many centimeters—is constantly bringing contaminated sediment to the sediment-water interface. We are only putting a few millimeters of sediment on top so these gradients will be maintained for a long time. For many years we can maintain these gradients and still see significant fluxes. This may postpone any improvement in overall quality of a harbor or estuary as a whole.

A major consideration here is speciation. What causes “things” (chemicals, particles, colloids) to be in the pore water, where they are subject to diffusion, or on particles? Some of these “things” are important for metals where we have anaerobic conditions so we will have a lot of “things” deposited as insoluble metal sulfide complexes that will leave the metal unavailable for these diffusive fluxes, or we have organics adsorbed onto particulate organic carbon. Some of these processes, which are fairly well understood, though not completely understood, are important in controlling these fluxes. We also have physical processes such as resuspension and desorption so if we have a more energetic system we can be resuspending particles into the overlying water where we have desorption into the water column. Again this could be important for “things” like metals if they exist in the sediments as sulfide complexes. As we expose these contaminants to aerobic waters we can oxidize the sulfide and release the metal into the water column. You can see where I am going with this. You can

think about how these processes might be altered if we put a cap on a cell.

A third process which people do not think about as often is submarine groundwater discharge. I think we are finding out that this is more common than we previously thought. There are places on Cape Cod where this can be the main source of fresh water to a harbor. If there are any contaminants in the pore water we can flush these out in the overlying water. It can be a very effective way of bringing "things" into the overlying water. These are the basic processes that might move contaminants from one place to another, or actually move them through the sediments.

Now let us talk about what happens when we put on a cap. We can talk about this in two ways; what happens in the short term and what happens over the long-term. For the short-term we need to worry about desorption or flushing during the dumping or consolidation period. As we are dumping the contaminated sediments into the cell, what kind of desorption could be occurring? My background is more with metals, so the question I ask is, are we oxidizing these metal sulfide complexes as they descend in the water column? And if we are, are we releasing metals into the dissolved phase? During their descent, are contaminants released in the dissolved phase? Or, during consolidation are large amounts of metals flushed out as pore water is squeezed upward from the cap?

One question is what are the rates. If you took a chemistry handbook and looked at the rates that some of these metal complexes can oxidize, it can be rather slow so you might consider that there is no problem. But a lot of these oxidation processes are biologically mediated by chemolithotrophic bacteria, just like those found in hydrothermal vents. To what extent are the oxidation processes being biologically mediated and how is this affecting the rates? These are potentially "knowable." I think we understand the processes, but I am not sure if people have actually done the calculations or set up a model and tried to see how important these things might be.

Now for organic contaminants. If we alter redox conditions, do we alter the K_d of, say, dissolved organic carbon? Are they going to be coming on or off of particles or redistributing? If so, we could also be redistributing the contaminants we

worry about; PAHs and PCBs. Again, how we have redistributed the contaminants, whether it is on a particle or off a particle, will influence what happens during the consolidation period. If we have processes that promote binding to colloidal organic carbon in the pore water, we could see a large flux of organic contaminants coming out of the cell. Again, I think these things are potentially knowable.

This raises the question of time scales. During the short-term we might have some larger flux of contaminants due to these processes but what are the time-scales of interest? We really need to integrate over longer terms, so over the short-term we could see larger risks but the benefits to be gained over the long-term might be much larger than the costs we are getting in the short-term. In other words, we are getting a short-term insult to the harbor but over the long-term we are getting a benefit in the quality of the harbor or estuary.

Now, let us move on to some of the longer-term processes. How is the molecular eddy diffusion going to be affected by the presence of the cap? We are going to have recruitment of benthic organisms that will bioturbate the sediment. The flux is a function of a diffusion coefficient and a concentration gradient. The processes occurring are molecular diffusion and biologically regulated diffusion. Molecular diffusion is generally going to be really small (it will take "forever" to pass through a cap). But if we have bioturbation, our effective cap distance becomes quite small. So we could have diffusion on time-scales of concern. If we have a cap that is too thin, bioturbation could bring things to the surface. So the questions are, what is this biological diffusion term, how large is it, and how much is it going to affect the ability of a contaminant to pass through the cap? Again that depends on the thickness of the cap.

A key issue is alteration of speciation. This depends on what form these chemicals take. As we bury things are they going to go anaerobic under the cap? If they do will we get more sulfides? If we get more sulfides, will we get more metal precipitated onto particles or as insoluble complexes that again will not be subject to diffusion. Or do we put things out into the pore water because we have changed colloidal organic carbon and speciation of PAHs. Again I think some of

these things are potentially knowable and modelable, but I am not aware of people who have actually gone in and measured these changes.

And again there is the question of speciation—whether a contaminant is on a particle or off a particle. When you change the redox conditions by burying the sediments underneath a cap it will affect speciation and availability for migration. We could also be changing nitrogen metabolism. You start promoting anaerobic denitrifying organisms, perhaps removing ammonia toxicity by taking ammonia into N_2 gas. Again, I am not sure on this. I know this happens in surface sediments but I do not know the extent to which it is amplified by making things go more anaerobic by putting a cap on top. You could also be changing mercury speciation. It is pretty well known that methyl mercury is formed by sulfate reducing bacteria, so by making these sediments more anaerobic are we promoting the formation of methylmercury, which is a more toxic and perhaps a more mobile form of mercury?

How is the cap going to affect another process that I talked about where we have resuspension and desorption? Again it is the same issues as above. How thick is the cap? What friction velocity is important?

Regarding submarine groundwater discharge, one of the Sea Grant Marine Center students, Chunhua Liu, looked at this and was able to show that when you have submarine groundwater discharge you have significant fluxes of metals through the cap into the overlying water. Again what is critical is speciation of metals. For metals to be subject to a flux from submarine groundwater discharge they need to be in the pore water and not on the particles. If we change the redox conditions, we change the speciation of contaminants and that is going to have a huge impact on the extent to which groundwater discharge will bring contaminants up through the cap and into the overlying water. Breakthrough times with the groundwater discharge, depending on the thickness of the cap and the groundwater flow, were hours to days, not weeks to months. But this was using sand as a cap, which has a limited ability to re-trap these contaminants as they move through. It might be different if you had more of an organic-rich finer-grained sediment as a cap. Admittedly, that would

be harder to lay down as a cap.

The bottom line is do we care? As an academic researcher I can start moving micrograms and milligrams of contaminants up through the sediments, but what we are really concerned with is when will these sediments have adverse effects? All of these considerations need to be tempered with “when do we care,” — what concentrations are going to be important in ultimately assessing whether these migration problems are a risk? It really takes integrating some of the physics, the chemistry, and the biology to really come up with how effective a cap is and to what extent chemical migration will be a problem.

COMMENT: There are two existing pieces of guidance on designing caps that came out of the program in the Great Lakes and the USEPA program. The processes that you have talked about have been extensively tested and modeled with the caps that have been designed in Puget Sound, looking at all of these factors including groundwater discharge, metal speciation and various other factors. Actually a great deal was written about this and it has been the subject of many presentations, several of which have been at Western Dredging Association meetings over the years.

Another comment is that I would like to put a different ending issue on the table and it is not about adverse effects to population, but it is simply about mass. We are talking about a lot of mass. The sediments themselves have a lot of volume and a lot of contamination on them—otherwise we would not be worried about it and all of these processes. If you look at one pathway you tend to be looking at very low concentrations. From a concentration perspective you have a hard time convincing yourself that there ever is an adverse effect to be observed, but from a mass transfer perspective, because these processes go on forever, we are talking about enormous movements of contaminant mass out of our CAD cells and into someplace else that then becomes the next site we have to worry about. For more contaminated sediments, the mass transfer volumes rapidly get into the tons per year for things like mercury, PAH and some PCBs. These are significant and what we are finding in design is that regulators are not asking questions about concentrations, they are asking Clean Water

Act compliance questions about short-term water quality impacts during dredging or post dredging. That is easy—you almost do not have to do the math. You can say you will not observe an adverse concentration threshold at the point of dredging or disposal, but you might find another Superfund site downstream in ten years.

RESPONSE: Right, but when contaminants come out of sediments where do they go?

COMMENT: My point is that it is not a short-term effect on biology at the point of dredging or point of disposal in the construction timeframe. It is long-term mass transfer, and when you are evaluating the effectiveness of the control measure the time frame of evaluation needs to go into the hundreds and perhaps thousands of years to look at mass transfer.

RESPONSE: It is not one or the other it is got to be both because ultimately a biological organism is going to respond to concentration.

COMMENT: I think if you try to design a cap asking only the short-term questions you are going to end up with one kind of cap. If you ask the questions about long-term adverse effects you come out with a very different and usually much thicker, much finer cap to get the protection that you are looking for. If you can tolerate the dispersal of mass from your CAD cell, if you have enough water circulation to actually dilute it you might be okay, because it will redeposit over a wide enough area that it will not cause recontamination at sediment concentrations that are adverse to organisms. If you do not have sufficient water circulation you are pumping stuff up into the water column and it gets entrained in the cap or stuck on particles that get redeposited near the site or on top of the cap.

COMMENT: It goes back to what you want the cap to accomplish, which depends on where you are. If you worry about the stuff leaking out and going into the environment, you have to remember that this site is not the only source of contaminants in the environment. There are all sorts of sources, including atmospheric deposition, and it is unfair to ask a remediation project, or dredging naviga-

tion project especially, to be “a little island of forever clean in this sea of contamination.” I am just saying that as we look at the physical and chemical processes we have to set objectives for this project that make common sense. For some of these caps you do not even need to worry about these processes because the only reason you are capping is that they may bioaccumulate if the organisms are in contact with the sediment and all these contaminants are so low in concentration that chemical flux is not an issue. But if we were doing a Superfund project, flux very likely would be an issue.

COMMENT: There is also a public outreach, public relations element here and we have to be aware that the information that we develop during design phases of these projects could come back and bite us badly, if we start predicting the mass loss from large CAD cells to be in the tons per year or thousands of tons per decade. Those are sound bites that get into the media and regardless of the importance of these losses in the context of larger sources such as storm drainage and atmospheric deposition, all of a sudden all eyes are on the CAD cell.

COMMENT: I just do not see where such a large efflux will be coming out of these cells. They are taking materials from a certain chemical environment, putting them into a cell and retaining them in that environment so I just do not understand where it is coming from. My one caveat is the groundwater issue. That has to be evaluated.

COMMENT: There will be some contaminants in the water that is fluxed through the cap but just because that water moves through the cap it does not mean that those contaminants move through the cap. Depending on what the cap is made of, that cap has absorption capabilities that will take those contaminants back out of the water that is flowing through the cap. That is all part of cap design.

COMMENT: But during the self-weight consolidation period there is probably no cap on the cell yet and a lot of water is moved out of the cell during that time.

COMMENT: But that needs to be kept in perspective with what mass is fluxing out of those sediments, and where they are before you do anything.

COMMENT: I understand that, but that is an issue about the existing environmental condition. I do not recall ever dealing with a regulatory authority that is willing to balance that condition with the disposal site condition, because the evaluation of the effectiveness of the disposal site is independent of the current environmental condition. That is a risk evaluating equation that is not currently in use.

QUESTION: Is there any work underway at WES that involves stepping back and looking at the bigger picture in terms of location and placement of caps? In terms of a decision tree to help you decide where it is appropriate, and in some location do you even need to cap at all?

RESPONSE: WES's site selection guidance is general because you cannot give specific site selection guidance. You have all these factors that we have considered but the issues differ from site to site, consequently trying to look at these problems within a system context is important.

COMMENT: One oil seep from a manufactured gas plant can be larger than the sum of all inputs of contaminated sediment disposal into the CAD cells.

RESPONSE: So when we ask our regulators to use common sense, I hope that they have this kind of data at their disposal.

Organic Chemicals

Phil Gschwend continued the discussion with a focus on organic chemical contaminants. He began by introducing a chart from a former student, Hsiao-Wen Chen. Chen had studied inputs of chemicals such as pyrene and benzo(a)pyrene into Boston Harbor and found that one of the biggest sources was from the sediment beds.

Several others students have said let us look at a place like the inner Boston Harbor and see what

the steady-state water concentration is and interpret that in terms of a steady state model that says here is what the river inflow is, here is what the atmospheric deposition is, and here are all the other sources and if you go backwards you ought to be able to see whether or not the sediments are a major source. If you do a mass-balance/box-model on the inner harbor, the inner harbor sediments, pre-dredging, do seem to be a big source. The point I am trying to make is that at least in Boston Harbor, contaminated sediments have historically been a problem and the dredging project potentially is changing things.

I could talk about resuspension but when we have studied resuspension we have found that it is sufficiently episodic or infrequent that, coupled with desorption kinetics, it is a small release compared to diffusion right out of the top of the sediment.

But I do want to talk about the issue of speciation. Chemists care a lot about speciation because that is one of the key factors in the chemistry, I would say, that dictates how much a chemical participates in certain kind of processes. The molecules that we are interested in are partitioning amongst larger particles and potentially smaller particles (colloids) and being dissolved. If I have bioturbation, I am moving the whole package (of large particles, small particles and water) around in the bed whereas if I only have molecular diffusion, I am only moving the water. It becomes incumbent on the chemists to understand a little about the kinetics and equilibrium to describe the partitioning for any chemical in any sediment that you happen to care about whether it is a sand cap or the bed underneath it. This boils down to being able to describe what fraction of any chemical is truly dissolved or in the colloidal phase or the particulate phase. The partition constant is particularly important. The constant historically for chemicals like dioxins, PAHs, PCBs, pesticides—non-ionic organic chemicals—tends to be a function of how much they dissolve in the organic matter of the solids from water vs. how much organic matter is in a sand or mud that you are interested in. So again this is a property of the solid and the chemical you are interested in.

The problem is that we now know, from many empirical observations, that that simple picture does not work for some chemicals. What I am

showing here are some data from Sue McGroddy when she was doing her Ph.D. work at University of Massachusetts Boston. She would go out to a place like Fort Point Channel, Boston Harbor and separate the pore water from the solid phase and she would measure the PCBs in the pore water and the PCBs in the solid phase. She would calculate what she would see in the pore water vs. what we would expect with different models. For a PCB, the models seem to be about right. (For this kind of thing you probably cannot get a chemist to tell you the partitioning to anything better than about 50 percent.) For chemicals like pyrene you have a substantial—order of magnitude—offset. So what is going on? Many people have suggested that it has to do with where these chemicals come from when they first enter the system. They are coming in conjunction with combustion-derived particles, e.g., soot or fly ash. That means that one could imagine a simple-minded picture that says that the partition constant is due to partitioning into the organic carbon plus some kind of interaction with “soot carbon.” To make a simple model—I am not sure that this is correct—the pyrenes of the world will dissolve from the water into the organic matter of the sediment and would interact with any sort of char or sooty material that had come from our diesel buses, street runoff, etc. So the overall K_d represents the sum of this partitioning into two media within the sediment beds. This simple model would be expected to explain the discrepancies that we see, i.e., that over 90% of the PAHs, and probably dioxins, in sediments are associated with soot.

Let me show you a little bit about this and some work that has been done. We collected about two dozen samples around Boston Harbor. We did a measurement of the organic content. After we collected these samples and dried them at 60 °C, we put them in an oven at 375 °C for 24 hours. At 375 °C any humic acid you put in the oven is oxidized, while any kind of soot you put in survives. After that pretreatment we reanalyze for the organic carbon content at 900 °C combustion and we call that soot. It is empirical, I do not really know that it is soot; I just know it survives 375 °C for 24 hours. What you see is that in all these samples there is some soot. (*He shows a slide, indicating the black soot.*) Something on the order of a tenth or a twentieth of the organic content of these sedi-

ments seems to be this other kind of carbon “stuff.”

Does it matter? Well going further, an MIT student, Amy Ricardy took this material and did a sorption experiment. She takes water, puts it in a cuvette and adds some pyrene and looks at the ability of the pyrene to fluoresce light. When they are absorbed in water, molecules can fluoresce light, whereas, when they are stuck on particles, they are unable to fluoresce light. So when she puts a control sample of water into a fluorometer she can see the fluorescence response of the molecule as a function of wavelength. Now she adds Boston Harbor sediment^{3/4} on the order of 100 mg/L^{3/4} and then she adds pyrene to it. After waiting a few days the fluorescence drops by 80 to 90%. So this 80 to 90% drop indicates that 80 to 90% of the pyrene has gotten stuck on Boston Harbor sediment and is no longer in the water. If we take the sediment that we cooked at 375 °C for 24 hours and put it in another cuvette and add the pyrene to it, we see that the fluorescence drops down to almost the same level that it would if we did not do the precook. This is consistent in that this material, whatever it is that survives 375 °C, is capable of really binding a chemical like a PAH and would dramatically affect how you would calculate its speciation.

Let us just wrap-up by saying that I think that the preceding story applies to combustion-derived PAHs as opposed to petrogenic PAHs. If I have a drop of oil leaking, I have still got problems from the benzo(a)pyrene in that oil. It is not clear to me whether the benzo(a)pyrene seeks out the soot that was already present and somehow associates with it. We have not figured that out yet but we do not think so.

I can speak to speciation effects on bioaccumulation. We are interested in clams, in this case *Mya arenaria*, the soft-shelled clam that digs down into the mud about 10 cm until fully immersed. We were interested in the issue of how much PAH or PCBs would be in the *Mya* versus how much we would predict depending on how I calculated the sediment's ability to hold onto the chemical. If I calculate partitioning using only the fraction organic carbon, the sediment holds onto the chemical about a tenth as well as if I include the soot effect. If soot is holding onto the chemical, it is not available to *Mya* in an “equilibrium way”. If you look at what we predict versus what we observe for a

set of PCBs and a set of PAHs in the same muds and with the same models, one would think if organic carbon is the story, (i.e., how hydrophobic the chemical is dictates everything) then all of the molecules should cobebe. But what you see consistently is that PAHs are predicted to be much more abundant in the Mya than we actually see and, ironically, the PCBs are too low in the Mya compared to what we see. So something seems to hold the PAHs back from getting into the Mya and something else seems to promote the PCBs getting into the Mya. Rachel Levine, an MIT student, Judy Pederson and I decided to examine, in the case of the clam, the idea that molecules may not partition into just the lipid in the organism. In the case of a clam, the lipid fraction is on the order of 5-10%, whereas it is 70-80% protein. If I were working with species that are very lipid rich maybe I should worry about normalizing for lipids, but clams are relatively low in lipids. Molecules like PCBs, PAHs certainly partition into proteins, though not as effectively per unit volume as into lipids. We went to the literature to figure out how to scale the partitioning of PAH and PCBs into protein. On the flip side I am arguing that these molecules also partition in the sediment into the soot carbon, not just into the organic carbon or organic matter. We recalculated bioaccumulation based on these consideration and found higher rates when they are taken into account.

I am trying to show that the above considerations affect partitioning and therefore speciation is very important and that, for example, if we want to decide if a cap is thick enough, we need to keep these factors in mind. We are still not to the stage, I would say, where we know exactly how these factors influence the different families of organic chemicals. But I think that it is pretty clear that they influence PAHs significantly. It is not very clear that they influence PCBs. PCBs often are not coplanar so maybe they do not interact with the surface of flow. Our initial look says that it does affect dioxins. Soot does seem to interact with dioxins and maybe that is not surprising because many dioxins are combustion-derived. I cannot say what pesticides do yet, as I have not looked at that.

COMMENT: In the industry right now, what we

look for when we are designing these sites is site-specific K_d information based on thin layer column leaching tests that take into account whatever is in the sediment: soot, carbon etc. Using book values will definitely take you in the wrong direction. One of the problems is the time frame for these tests. In the real world people who are permitting sites and designing projects do not leave enough time for thin layer column leaching tests, and the industry is generally defaulting to sequential batch leaching tests because these can be done in a week as opposed to three to six months, depending on sediment permeability.

RESPONSE: It turns out that desorption kinetics are a strong function of other properties about how you run the experiments so there may be ways to set those experiments up that will meet the time constraints.

COMMENT: Maybe so and that would be a conversation I would like to have with you and then I would like to have it with scientists from WES and the USEPA to figure out how we get those alternative experimental protocols into the guidance so we can actually use them in the regulatory context.

RESPONSE: I would argue that first we put it in the peer-reviewed literature and take our beatings there, and then get it into guidance.

COMMENT: Your comments about soot carbon are excellent. One of the things that is being done and modeled and probably will be used within the next couple years is the use of carbon particles to control PAH flux in caps. If you want to design a cap that is more than just sand or silt, it can be done and there is a lot of work going on. These kinds of caps, while expensive, can be thinner and you can do more with them, you can get more effectiveness out of the cap if you design it with some specialty particles.

COMMENT: How come K_d is so big for pyrene and not for PCBs?

RESPONSE: I think it has to do with the ability of the PCB to sit down on the flat surface of the carbon. Conversely, the dioxins are all coplanar.

QUESTION: Is gas production within the cells and its transport to the surface a potential vector for contaminants, particularly organic pollutants? Maybe those that have some field experience would want to touch on that.

RESPONSE: It is a big issue and one that we have not looked at well enough to know what kind of mass travels along with methane bubbles. A lot of the sites we look at have tremendous methane production and in a literature search about a year ago we found very little on this.

COMMENT: One thing that happens with cohesive, oily sediments is that you get bubble traps. Bubble traps become pathways for oil emanation as well. So you have a methane bubble that moves into that bubble trap with a little bit of oil on it and you can push out that oil. If you have a site with oily sediments that is something you really have to look at.

COMMENT: They installed some collection devices in one of the CAD cells in Boston. I have not seen any of that work. It happened late this summer but it may give us some information in the next year or two.

RESPONSE: On the chemical side I do not think it would be difficult to calculate at least the concentration of organic chemicals in those bubbles if you knew the volume of bubbles emanating. But if there were a surface-active component on the bubbles that actually contributes to the transport, things would be more complicated.

COMMENT: My colleague and I are laughing because we can think of sites that we have been out on where at low tide on a sunny day it is like being in a glass of club soda—there is so much methane coming out of the sediments.

RESPONSE: There are a lot of non-contaminant surface-active chemicals that will help in the transport. The other thing is that the sediments are cohesive, probably not even behaving like a porous medium. Probably behaving like a porous media to a degree but there are some macro-structures here where most of the material is moving and

analyzing that porous media will under predict what comes out.

Any other comments on chemical migration?

COMMENT: From what I heard it did not sound like there was any point in doing post cap monitoring for contaminants. The rates of release are so slow that we do not expect much in the water column.

COMMENT: I generally agree with that, but it has not stopped us from installing flux chambers on top of a lot of caps and non-capped sediments in order to get a better appreciation of what is going on. And without exception the concentrations we have measured in the flux chambers are much lower than any kinds of modeling would predict. Again, indicating that the way we analyze these sites is very, very conservative.

COMMENT: I think it is safe to say that every cap site that has a real environmental concern with it, like a Superfund site, all those cap sites are openly monitored and they will be monitored not only with things like seepage meters, but also they will be cored at a frequency that will confirm that there is no gross movement of contaminants up into the cap.

COMMENT: One problem with cores, though, is that with sandy cap material, you could have a large flux of material that is of ecological concern, but you do not have a lot absorbed onto the sand particles. Hence your core might come up with low concentrations when the flux is actually higher.

COMMENT: What goes away you are not going to find, but that is not the only issue with some of these sites. With some of these sites the issue is recontamination of the cap.

COMMENT: Is this correct then, based on what we heard. There would be no recommendation for post-cap water column monitoring but in fact there will be?

COMMENT: Not water column, you will never see it in the water column.

COMMENT: Just a second on that. What about the possibility that when metazoans are stirring the cap you do not actually successfully measure that in a seepage meter or in a bell-jar type of experiment? I would argue that the water column monitoring is a great big bell jar experiment. You need to know the flushing balanced against the flux.

COMMENT: But your sensitivity is reduced.

BIOLOGICAL IMPACTS AND RESPONSE

Judith Pederson, MIT Sea Grant

I am going to take you from the equations and quantitative data to a topic that is a bit more philosophical and should segue into some of the discussions this afternoon. I am going to raise three questions:

- To what extent are benthic organisms affected by pollution, contaminants and physical disturbances?
- How robust are the observations we have here in Boston Harbor compared to other areas?
- And finally can the data on the benthic organisms and sediments be used in some way to assist managers as they develop policy?

This morning, presenters identified the behavior of sediments during dredging, disposal and consolidation. From a biologist's perspective the grain sizes, depth, and salinity reflect what biota one would expect to find. (*Pederson shows a slide of benthic organisms found at various depths*). This is a sketch of the types of organisms that you would find in the soft sediments in a healthy Boston Harbor or in the Northeast area. It shows the various depths in the sediments to which the organisms would feed or interact with particles, pore water, and associated contaminants. Most of the organisms are in the first few centimeters but some organisms, *e.g.* the polychaete *Clymenella*, burrow to a depth of 20 centimeters reworking the sediments. The slide also shows you the different types of feeding mechanisms used by the infauna. Some are bottom feeders (head first in the sediments) and deposit reworked sediments on the surface, some are deposit (surface) feeders and

may or may not carry surface sediments to varying depths, some feed in the water column, and some use a combination of feeding behaviors. (*Another slide is shown of selected contaminants at depth*). This slide is from the USEPA study of contaminants in Quincy Bay, Massachusetts. There are two points that I would like to make. With some chemicals, such as lead, you can see higher concentrations at depth than in the surface sediments, reflecting the removal of lead from gasoline in the 1970s. The second point is that for some chemicals, particularly PAHs, PCBs and petroleum hydrocarbons, concentrations are higher in the surface sediments than at depth representing ongoing deposition. What the slide does not tell us is how available the chemicals at depth are to the organisms, *i.e.* how does diagenesis change availability?

The traditional way of evaluating biological impacts from a dredging project such as the BHNIP, is to follow the USEPA and USACOE protocols. A tiered approach examines the historical record, grain size, chemical concentrations, and biological effects when organisms are exposed to the sediments. If warranted by extremely high concentrations of contaminants (*e.g.* Superfund projects), there may be a need to examine effects on the community. What are the concerns and how valid are these tests? In yesterday's presentations, speakers identified the effects of contaminants on mortality and bioaccumulation as surrogate tests to evaluate potential effects on humans, ecosystems and endangered species. Much of the interpretation depends on acute responses such as mortality rates and significant bioaccumulation. These have been criticized as not reflecting how organisms respond to concentrations in nature. However, even though we have data on biochemical and physiological responses to contaminants, we are not able to translate these into universally accepted tests in lieu of the current testing protocols.

What did not get discussed yesterday is how organisms respond physiologically, but are not killed by exposures to low levels of contaminants. Laboratory studies indicate that low concentrations of contaminants in the water column may alter normal chemical reception that affects behavior and reproduction, and interferes with immune responses. For example, when lobsters are exposed to petroleum products, they alter their behavior. They ignore

danger signs, may wander erratically, and remain exposed to predation. We have no way of integrating physiological responses to low, chronic exposures in current testing protocols.

The cumulative impacts of non-lethal concentrations on populations of marine organisms are also poorly understood. One study showed that PCBs decreased reproductive output by approximately 50%, but how this affected the population is unknown because recruitment may result from larvae outside the impacted area. In the larger context, as discussed by Phil Gwschend, Rachel Levine's reexamination of bioaccumulation in *Mya* illustrates (1) simplified formulas do not reflect observed data and (2) that more work needs to be done to integrate the physiology of organisms with chemical contamination.

What do we know about benthic communities in Boston Harbor and have they changed as a result of capping contaminated sediments? Amanda Borque, a Harvard University student, examined benthic communities in sediment from the pilot cell and capped and uncapped cells. Her preliminary data suggest that diversity and biomass remain low. We used grab samples to look at the numbers of organisms present and found that they were very, very low in abundance and number of species. And they were typical of what you find throughout Boston Harbor. We found only 1 to 7 species of the 15 common species that are typical of pollutant tolerant communities throughout the Northeast. It did not really matter whether we were in or out of the cell in terms of the ambient background concentrations. We also conducted sediment profile imaging that supported the data on organism distributions from our grab samples. The very soft sediments that had just been deposited from the dredging activities had virtually no life. The capped pilot cell benthic community was comparable to "ambient" communities that had not been dredged. Thus, we had a pollutant tolerant community prior to dredging and it appears that we have one after dredging. Amanda's data and that of the consultant to the BHNIP showed no significant difference in chemical concentrations in sediments in the cells. Others have already speculated on the spreading of contaminants from adjacent undredged areas. For organisms, these fine-grained

sediments are more available and have higher concentrations of contaminants than the cleaner, larger-grained sands of the capped material.

This discussion has focused on contaminants and the risk they pose – the subject of another concurrent workshop. Some of what we observe may be due to other factors. The nearly azoic conditions found in some areas of the inner harbor, e.g. Mystic River, may be due to low dissolved oxygen found at the sediment/water interface. However, measurements of dissolved oxygen throughout this study would suggest we do not find anoxia and hypoxia except in cells that have newly deposited sediments. Because low dissolved oxygen at the sediment/water interface is likely to be found throughout the harbor during the warmer months, it limits our ability to examine species richness and diversity with contamination.

What are the implications for future dredging activities? There is much criticism of current testing protocols and what they tell us about dredging impacts on biota. Yet, we have not adequately integrated data on acute and chronic responses into protocols that are meaningful and acceptable scientifically. Clearly this should be a high priority. Equally surprising is the scarcity of monitoring data on the benthos from capping experiments. Without data we continue to debate the effectiveness of caps and whether we should or should not cap.

The question of scale also emerges. Compared to the Gulf of Maine, Boston Harbor, and especially the inner harbor is a very small area. However, this obscures the real issues of what is happening locally. Do caps add a measure of environmental protection or do they have no effect? What temporal and spatial scale should we be examining? In Massachusetts we have accepted the "short-term pain" of dredging impacts on biota in exchange for the "long-term gain" of benefit to the project and maybe to the biota.

I would like to open the discussion to perspectives on some of the biological issues relative to the dredging and disposing of contaminated sediments and capping of CAD cells.

QUESTION: How many cycles have you gone through for colonization before benthic sampling?

RESPONSE: The times varied from decades (for ambient sites) to weeks for uncapped areas. The pilot cell cap was in place for one year and some of the cells that had just been capped (cells M5, M12, and M2) were in place for a few months. The Supercell, which had not been capped, had newly deposited material.

We also looked at the levels of contaminants in the various cells.

QUESTION: Is your stormwater treated here?

RESPONSE: We have about 80 combined sewer overflows. A fair number of them have been diverted to a treatment facility and no longer discharge. Some still discharge, either untreated or treated with chlorination, and some with grit removal. We are only now addressing stormwater discharges, but these are a significant source.

COMMENT: To do a massive cleanup of the harbor one would have to look at the potential for recontamination of the harbor because of untreated runoff. The primary rule of thumb for a cleanup anywhere is: eliminate the source first.

RESPONSE: Right, and what we have done in 1991 was eliminate our sludge from being dumped back in the harbor. That removed a fair amount of carbon out of the harbor, and once that happened, we saw amphipods colonize a major part of the harbor. But we have not seen a lot of change since then in terms of the species. In September of 2000 we moved the outfall out into Mass Bay and people say they are already beginning to see an effect, but we have not quantified the effects of that change.

COMMENT: The caps are commonly sand; they are not recreating the habitat that was there but rather a new habitat. Another example is in New York where they are having problems throwing out clean clay. There is no organic material in there so there could not possibly be organisms, yet nothing is contaminated. Philosophically, one of the questions is when you are designing the cap, is it acceptable to create a new kind of habitat that was not there before, or do you have to start constraining yourself and saying we want to not only cap

this material but create an environment that should have been there pre-anthropogenic input?

COMMENT: I do not think there is anything that is pre-anthropogenic here.

RESPONSE: I would contend that for CAD cells, after a few years the surface of that cell is going to look like what is around it both in terms of grain-size and contaminant levels.

COMMENT: For Boston Harbor CAD cells that happened on the order of months. And we spent between \$7 and 10 million to put sand there for the short-term. Did we get \$10 million worth of benefit? I want to look at these things from a broader scientific perspective. Was there something we, as a society, could have done with \$10 million to create a better benefit?

COMMENT: I want to try to answer the question, but as one of the people who contributed to the regulation of the development of the permits for Boston Harbor, I want to preview some of the conversation we will be having this afternoon. Take everything you talked about this morning in all of its sophistication and technical complexity—whether it is biology or physical or chemical—and put it in the environment of extraordinary public concern, put it in the environment of overworked regulators, overworked and undereducated compared to the level of information that you folks are working with, and then put political pressure on top of all that. There have been all kinds of alternatives and approaches kicked around here this morning, but there are no “peer-reviewed” guidelines, no perfect approach to any of this, and neither industry nor the Corps folks who work on this for a living can tell us exactly how that would be done. We look to that source of information to inform what we do. In the absence of any kind of agreed-upon approach, what are we left to do? Build it big, built it deep...and then monitor it. All of this is wonderful but it comes down to a very simple, very human, very pragmatic approach. If we are getting stomped from all different sides, and this stuff really is tough and tricky, there is a way you can back off and take a very pragmatic approach. Throw three feet of sand on it, monitor

it, sit around a table as a Technical Advisory Committee with the guidance of an Independent Observer, let everybody look at, try to respond as best you can in real time, and go from there.

COMMENT: From a public (and agency) acceptability perspective, in order to make the project sell, that did it. But I would like to step back and say, in retrospect, we did spend \$10 million of public funds and it is useful to ask, did we get \$10 million dollars worth of benefit? In terms of environmental benefit, what did we get?

COMMENT: I think that is a great question because now I am no longer a regulator, but a proponent, and I do not want to spend \$7-10 million on a cap. But what I want you to tell us is, here is how you design a cap that minimizes the capital costs and maximizes the benefits in a way you can document for the folks in the city you are trying to work with.

QUESTION: Is there a retrospective plan for this, because you laid out a series of plans and decisions and what they were based on, and now we have some information that we did not know before. So what is the retrospective process to help address the questions?

RESPONSE: One little piece that we are doing is taking some money out of the Seaport bond and we have asked ENSR to go back through all of the information that was developed over the course of the project and, as we work with the Massachusetts Department of Environmental Protection (MADEP) to develop new dredging regulations, try to do exactly that thing. Here is the level of effort; here is the information we gained. What was worth it, what was not worth it? What are the simple things that regulators can use? What are the tools that can tell you what is happening in the cell? What can be done that does not require a team of the best and the brightest sitting around the table every two weeks.

COMMENT: Maybe I can recast an earlier question. Practically, could you have capped this with something other than sand that is closer to native sediments? And would that have worked from a physical standpoint? Or, alternatively, since the

latter cells were deep and there is a strong gradient in the quality of sediment that was being dredged, can you concentrate on putting the most contaminated sediments deeper, and the cleaner ones on top so you effectively have a gradient of a cap of natural materials?

COMMENT: The easiest thing to do would be to use the cleaner sediments from the outer harbor. Instead of taking them twenty miles offshore we could use them as the cap. They are closer to the native material. It is cheaper to do. You get the same thing.

COMMENT: Can I give you the regulator's point of view? The cap needs to be there because of public perception. Whether or not it is justified scientifically does not matter. People want to know that it is capped and sequestered. You cannot get beyond that, at least here in Boston.

COMMENT: But you can call anything you want to a cap.

COMMENT: That gets me to a second point then. The regulators need a clear, distinct, easy way to tell that a cap went on, and right now the best way we know to do that is with sand because it is simple and it is visual.

COMMENT: If you want a visual horizon you could place a thin sand layer and that would be evident. Just as a visual layer. Anything above that is a cap.

COMMENT: You can place fine grain materials. However, the problem with a site like this is that, if you generate that fine-grained sediment by mechanical dredging, and it remains cohesive, it is going to be difficult to let that cap accumulate on the surface without causing a failure. It is not like spreading sand. You could use some other sort of placement mechanism, perhaps some sort of re-slurry on the barge. The problem you have there is that fine grain cap materials are going to erode easily and you are going to have the same situation you had with the contaminated sediments. You are going to have to let the cap consolidate for some time to gain strength before you can continue to

build it up. But you can build caps out of something other than sand, and if your objective is visual you can still put a layer in there so you can see it.

COMMENT: Can we get back to biology—from an earlier questions? If you look at Gene Gallagher's (University of Massachusetts) work and certainly what David Shull discussed yesterday, it appears that water depth, sediment type, and so forth are important to what organisms you find where. The question then is, do you or do you not cap in Boston Harbor? Do you change the community because you are changing your substrate? This was asked early on in the process but should be examined in the context of scale. How much surface area do these sites take up? And will they or will they not recap themselves with the fine sediments?

COMMENT: In some cases they have done a site, not just to get rid of dredged material, but also to actually improve an area such as raising the bottom to an intertidal depth. I do not understand why the creation of a new habitat that would be better than it was before can be considered a bad thing, just because it is not natural? There seems to be a lot of controversy over creation of new habitat.

COMMENT: I think it has to do with state regulations, or with USEPA. If you are replacing degraded subtidal area with degraded intertidal habitat, they are still going to argue that unless there is a massive upside in the benefits, the potential value of an improved subtidal sometime down the road greatly outweighs whatever immediate value you are getting by creating intertidal.

COMMENT: I would just like to add something to what Judy Pederson was saying about changing the substrate type. It is not only what is colonizing the substrate (and I come from a fish ecologist perspective) it is how mobile organisms will use it. When you come to fisheries that is what is of concern.

COMMENT: Do we need to cap?

COMMENT: I think we have heard a lot of discussion. It depends upon the situation. If you are designing a remediation project, capping may be a

critical component. If it is going to be a Boston Harbor situation were you are going to see rapid resedimentation and rapid return to sediment very similar to what you just finished capping, it becomes a bigger question. It may be necessary because of the political and regulatory climate, but looking at it from a "what are you accomplishing" perspective, it is open to a lot of discussion. I think we need to continue to discuss that.

COMMENT: If public perception says cap it—and they are happy, they are comfortable and they feel safe—then it is a lot of money well spent.

COMMENT: That goes back to the objectives of the project. If the objective of the project is public perception, a one-foot cap may have been enough.

COMMENT: We talked a lot about bioturbation. At the outset it is one of those things that you need to be aware of. You need to design for it because it does affect various rate processes, it does affect whether or not the material remixes to the surface. But it may not be much of a concern in some places and you may have only minimal bioturbation in some places.

COMMENT: But is not this a short-term/long-term thing? I mean if you are looking at Boston Harbor, you are not going to change your community in the short-term, but if a harbor continues to improve then is bioturbation a concern?

COMMENT: If the purpose of your cap is isolation, bioturbation is a concern. Period.

COMMENT: Yes and you need to design for your specific site conditions.

COMMENT: We talked about dissolved oxygen (DO). It is an open question. We do not know at this point whether this is a driving force in community structure. There was some limited monitoring done in Boston Harbor. Longer-term follow-up will be of interest, certainly, if these cells are sedimentation sinks. They also may be sinks for biochemical oxidation demand. Whether that can have a marked impact on the overlying water column and how much is an open question.

COMMENT: The benthic organisms are living right at the surface or on the surface so you do not have to go very deep to sample—a couple of centimeters will do it. If you do not have any oxygen down there, you are not going to get many organisms, period.

COMMENT: When we put our oxygen probe into the sediment you get readings of zero.

COMMENT: So you do have DO measurements that were zero?

COMMENT: These processes occur right near the surface of a capped or non-capped cell. What kind of long-term monitoring has been done on cells to look at this kind of response over time? Or what could be planned?

COMMENT: Just to add something. Monitoring for a parameter like DO needs to be done continuously. Point samples of water quality, in my opinion, are fairly useless because they can change. And DO in the matter of hours can wipe out certain creatures. You need to be able to monitor that at a fairly consistent basis for the long-term. That is an issue. It needs to be a continuous time series.

COMMENT: I would agree...unless you can monitor something like the benthos that may integrate impacts. If they are there and then not there, for example, as indicated by a sediment profile camera you can extrapolate.

COMMENT: You are asking what you need to monitor. I am just saying that if you are doing something over the CAD cell, you need to be able to compare that to what is around it.

PROJECT PROPONENT/REGULATOR INTERACTIONS

Deborah Hadden, Massachusetts Port Authority; Susan Nilson, CLE Engineering; Steve Wolf, ENSR; Deerin Babb-Brott, Massachusetts Coastal Zone Management

This session focused on recent experiences with the Boston Harbor Navigation Improvement Project. It began with an overview by Deborah Hadden followed by shorter presentations on the need for single agency point of contact (Sue Nilson), the perspective of the project Independent Observer (Steve Wolf), and perspectives from a state regulator (Deerin Babb-Brott).

Overview

Deborah Hadden: I will start with a very brief introduction to the Boston Harbor Navigation Improvement Project (BHNIP), which I am assuming most people know enough about by now. Deerin and I stepped back and looked at Boston Harbor, as well as other projects, and identified what we thought were the challenges to the regulators, the challenges to the proponents, and issues that we thought needed to be carried forward, the things we had done well or could do better next time. After my remarks, a couple of panelists will make three-to-five minute presentations and then we will open it up to discussion.

The BHNIP basically involved removing about 3 million cubic yards of sediment from Boston Harbor. Roughly 1 million cubic yards of that was "contaminated" and we placed it in Confined Aquatic Disposal (CAD) cells within the project footprint. That is probably the most interesting point to know if you are not familiar with the project. The remaining 2 million cubic yards were "clean" Boston blue clay and these went out to the Mass Bay Disposal Site. The project broke new ground, at least locally, in a number of ways; for example, CAD cells being used this way, within the project footprint, within or below the navigation channel, was unique in its own right. Locally, no one had had any direct experience with a project of the BHNIP magnitude or using CAD technology. Also the way we worked through the overall

planning and permitting approach was a little different. I think the approach was more collaborative on the proponent, regulator, and public sides than we had seen before. There was no other way to get a project like this done as quickly as we did. I think that although we learned a lot, it was done as well as it probably could have been done with what we knew at the time, and I think that the collaborative approach was a real key to that. The final, most important point is that we need to learn from the experience. We did not do things perfectly; what could we do better next time?

We identified some of the challenges to the regulators as they were going through this project and trying to work through the planning phase with us, identifying disposal solutions and then actually developing specific permits. One challenge is the lack of CAD-specific regulatory guidance and maybe that should be on the bottom of the list because it was pretty far along in the process before we zeroed in on the CADs. For much of the process, because of the magnitude of project, there was not always the level of detail in the regulatory guidance that we could have needed, but once we got to the CADs there was nothing. We lacked predictive tools. For a project of this type and size we just did not have these tools in place. And I would add that the baseline data that were needed to make those predictions were not there. An incredible amount of baseline data was not available so you cannot really do an impact analysis. There were scientific gaps, and lack of experience with monitoring CADs. So it is hard in developing the permits to even know what to ask for.

All of the challenges to the regulators become challenges to the proponents. Second, there is the conservative regulatory approach that led to the discussion of the cap and whether to cap or not to cap. In the end we decided to cap. I agree we had to do that to make the project go forward, but I think from the regulator standpoint that falls into the category of having to take a conservative approach. With a \$10 million price tag that is a hard pill for a proponent to swallow. The lack of definitive impact evaluation and project performance standards are issues, and again I would add to that a lack of baseline data. Multi-agency interests and perspectives were huge hurdles. We did things on this project that helped us get around that, but I

think in general that is a big issue. Conflicting regulations and policies were another issue. Even within one particular agency different departments have different sets of regulations; when you get in an area that does not always have a specific set of regulations, it becomes an issue. And finally, the negative public perception of dredging and the inability to convince the public, no matter how much data you have, of certain things. There is just a perception that dredging is bad and it causes impacts, and that is a high hurdle to get over.

There are a couple of issues that came up on this project. One is the need for flexibility. I think we had an incredible amount of flexibility on this project. Some of that came from the fact that Massport, being one of the co-proponents of the project (with the Army Corps), as a state agency, was able to go to the other state agencies and say we need something different here, we need to be able to work with you. I do not think every proponent has that advantage but it made a big difference here. We had one person that took the lead for us in pulling all the agencies together and getting consensus and it gave us one person to go to. If representatives of the different agencies, particularly at the state level, were saying different things, that one person got them around the table and got them to consensus so they were speaking to us with one voice and that made a big difference. As we went along in the process there was an incredible amount of flexibility incorporated. Often the scientific data that you need to make a decision was lacking, and we were given the ability to move forward stepwise by having permit conditions and checks and balances along the way. In doing so we were able to improve the project as we went along and I think you rarely see that happen. As a result I think the project went along much more quickly than it otherwise would have.

The Technical Advisory Committee on this project is something we would point to as one of the main reasons this project succeeded. We had advisory committees throughout that changed depending on the needs of the project, starting with the broader public and more industry groups. As we got into the permitting it became a very focused group of people who had been involved for years, knew the issues and could really contribute valuable advice. The state actually put that committee

together with people who could really contribute. I think a technical advisory committee can really help or hurt a project and this one was structured very well and we should try to learn from that and use technical advisory committees in that way in the future.

The need to continue to advance the scientific understanding really jumps out at me. Through these discussions it is clear that we know a lot but we also do not know an awful lot. If you are trying to move forward with a project, at some point you have to make decisions and move forward with what you do know. But at the same time you need to pinpoint what you need to know, prioritize that, and keep learning from it. As proponents I know we fought with the regulators a lot about not wanting this to be a science project and not being able to afford to pay for that, but at the end of the day we learned an awful lot and I will now concede that it was necessary. These are just some issues I want to bring to the front, and the panelists will focus specifically on some of these issues.

The Need for Single Agency Point of Contact

Susan Nilson: What I would like to spend a few minutes on today is a concept that was used successfully in the Boston Harbor Project, which is a single agency point of contact. This project was a little bit different because it had the Technical Advisory Committee. Steve Wolf will discuss this when I finish, but I think that is something we should learn from and apply in future projects.

A large number of public agencies either comment or actually issue permits during a dredging project. *A slide was shown of different agencies.* As you can imagine it gets very complicated for the project proponent to see their way through this. Each of these groups represents varying interests and has different regulatory jurisdiction. They do not all comment directly to the project proponent as I have shown here. Some comment through other agencies, but the end result is that the proponents need to see their way through to end up with permit requirements that are consistent and that once their project starts up they are able to comply with the multiple conditions that have been set forth. For the Boston Harbor Project in particular,

the complexity of the project as well as its innovative approach lead to a high level of interest from many public agencies as well as private organizations. The review of the project from the regulatory agencies was also challenging. Existing data were lacking and there was not a clear policy in place to handle the proposed CAD cells. I think this left a lot of the agencies questioning how they could address all of the comments that were received, protect their groups' interests and still come up with permit conditions that were feasible from the proponents' perspective. What the proponents were seeking, of course, was consistency among those regulations. Which leads to what resulted, the requirement for a real balance. Again we have the multiple interests and perspectives on one side, and we have the proponents looking to go forward with the project and have something they can actually put into place on the other side.

For the Boston Harbor Project, this was reached after years of planning and what resulted in essentially a single document. I do not mean to misspeak on that term because there were many different permits for this project, but the real guiding document, from my perspective on the monitoring team coming in during the first phase, was the water quality certificate. That sort of became the central clearing-house for permit conditions. We went through all of the permits and what we ended up doing was being able to look at the water quality certificate and see what really had to be done in the field in order to comply, in terms of dredging, disposal and follow-up. Although it was difficult to meet those conditions, they were clear.

The other issue was, as questions arose during the first phase, having one point of contact we could go to. That was MADEP. We knew that if we had any questions on the monitoring data or who to contact, we were able to go through MADEP, and we knew that then the Technical Advisory Committee would be brought in and all the agencies would comment, so the response we got was a consensus. From the proponents' perspective, and from a monitoring perspective, we have a single agency point of contact. This system worked quite well for this project and what we are looking to do is pull out some of the ideas and take them forward on other dredging projects.

I work on a lot of different projects of all sizes.

Typically we are on the proponent end of things, sometimes we come in after the fact and we are working on the monitoring as we did for this project. I think what we took away from this was the importance of using joint processing meetings or using the agencies as a group to try to gather a consensus. It worked very well on this project with the Technical Advisory Committee. I think what might be interesting to add in the future would be a single agency point of contact, perhaps following from the joint processing meeting. Whether it be through Coastal Zone Management or MADEP, it is important to establish some sort of guideline that will enable proponents to go to one person or one agency and feel their way through the conflicts that come up between the different regulations.

Lastly I think it would benefit everyone—the proponent and the different agencies—to have feasible permit requirements that can keep projects going but everyone can still feel like they had a great level of input into those. So that is the idea of the single agency.

The Perspective of the Project Independent Observer

Steve Wolf: I am just going to give you a little bit more detail than I did in my talk at the beginning of the conference on how the Technical Advisory Committee (TAC) worked and the interaction with the Observer. Again there is a whole list of folks in the various groups here that worked together to hammer out the actual permit for the project and it is a varied group. In addition to regulators, who may or may not have a strong background in this particular arena, you have your environmental groups, some of which I would say are on the more extreme end in terms of picking up a certain issue that might throw a wrench into a particular project. Those folks were all pulled in together in terms of hammering out what the monitoring would look like, how the project would take place, and when my company came aboard as an Independent Observer that group of people was already pulled together. So mechanically how it worked was that the permit required that there be an Observer for the project. Not oversight (the Corps provided that), but an observer to look at things from an

environmental point of view, and look at the permit that was issued for the project and make sure that the various components of that permit were actually being followed. Money came from the proponents, Massport in particular, through Coastal Zone Management (CZM) who turned to Deerin who selected an Observer. That person would report to CZM as well as to the whole TAC.

In the beginning that group met every couple of weeks as the project was up and going. Again there was a lot of concern and it was a group of often 15 to 20 people meeting for several hours to go over the details of the project. It is probably easiest to just give you a couple of examples so you get a sense of how it actually worked. Here is a picture of the environmental bucket used to remove the silt (*slide*). One of the requirements in the permit was that the bucket be equipped with certain electronic sensors. One was a depth sensor that would tell how far off the bottom it was so the operator would not partially fill or overfill the bucket. Another requirement was a closure sensor so that if the bucket tried to close on debris or was otherwise not closing properly, the operator would know. This is an environmental bucket designed on one hand for a cleanup operation, yet this is a production scale navigation project, so the operator is interested in production and doing this quickly. It really was impossible to keep these instruments intact, working at a production rate. After the first night of dredging the electronics were gone. That could have been a showstopper. The MADEP could have come in and said this does not meet the permit conditions, stop work. But I think partly because there was an Observer there at the outset of the project, and partly because we were able to communicate the information that things work pretty well—the operator knew where the bucket was based on the amount of cable out, the operator also knows if the bucket is closed or not—you can still manage that level of control and ensure that water quality and the overall objectives are being met without having those electronics. The project in this case was able to go forward without really skipping a beat, and nobody felt that somehow the environment had been compromised. So that is on the end where having the TAC really helped keep the project moving in spite of some difficulty.

On the other end of the spectrum is something

I mentioned in the other talk and that relates to having a cell out in the waterway where vessels are passing over. One TAC member really felt strongly about this. Through discussion it became more and more of an interest and what came out of a series of meetings was a requirement for a more detailed investigation. One thing led to another and what we got out of it was a very detailed report. This was something that the project proponents were not eager to do in the beginning because it was another costly measure for the project overall, but again it kept the project moving forward and contributed to more useful data coming out of it for future projects.

QUESTION: Has the concept of an Independent Observer been used previously?

COMMENT: I think it has been used on some other projects but not on a regular basis. The way it was presented early on to us by the agencies was as follows. Look, you guys are the proponents (The Corps and Massport); no one is ever really going to believe you (meaning the agencies). You are out there working 24 hours a day and it is just really hard for people to believe that there are not things going on out there when no one is watching. Even in the middle of the day, no one is out on the water, it is in the middle of the harbor, you cannot see it from the land side. The agencies felt that it was really important to have someone who was considered independent, who could be out there observing, and that both the agencies could look to, because they did not have the resources to be out there monitoring. The same goes for the public.

COMMENT: I have to say that we, Massport, were incredibly resistant to the idea early on. Particularly to having to pay for it, but also to having someone who would be "Big Brother" and would be out there trying to catch us off our guard. The reality is that it did not work that way at all. The credit really does belong to Steve. I think with a different person, a different firm, it might not have worked so well. I have heard of a lot of examples where both the TAC and the Independent Observer concept have not worked well.

COMMENT: It sounds to me like you have to be part scientist, diplomat, politician, etc.

COMMENT: When the agencies came to us and said that we needed to do this, we did it reluctantly. It turned out to be one of the best things that could have happened because issues like the one Steve gave with the bucket came up all along. What was in the permit just did not work in the field and the requirements could not be met. Without a person to help mediate and bring people together and explain the facts and get a consensus on where to go, I just do not think we would have gotten over a lot of those hurdles without having to stop work.

COMMENT: I think the hardest thing, a thing that Steve was able to pull off, was not becoming invested in one or another of the aspects of the project. Steve was able to take a clean look at things and keep in mind that the objective was to make the project work.

COMMENT: I imagine there would have to be status reports?

COMMENT: Yes, Steve did that. Weekly emails. If an issue came up we would immediately email Steve, discuss it, and he would send out an email to the TAC members saying, this issue came up, this is what we are thinking, let me know if you have any feedback or we will talk about this at the next meeting. There was a little clause that said, in the event that the TAC is unable to achieve consensus on a major issue, because they would have to take direction from somebody, they would take direction from CZM, but that would require an extraordinary event.

RESPONSE: That was up front. And I think the other overlying notion was that, at the end of the day, the regulations were the regulations and the regulators were the ones that ultimately interpreted those regulations. That is really important because a TAC run amok could be a bad thing. I think there were a few times that that had to be said, because people were pushing for things and one of the regulators had to make a call. That was clearly stated up front though and I think that made a big difference.

Perspectives from a state regulator

Deerin Babb-Brott: What I want to try to do is take all of this, everybody coming to work together and this feeling of trust, and figure out how to institutionalize that and memorialize that in regulations going forward. How do we replicate the Independent Observer process? Or how do we replicate whatever it was we thought was important? Just a second of context. We will have dredge control management plans direct from the Governor's office for the lesser ports of Gloucester, Salem, New Bedford and Fall River (in MA). As a complementary effort to that, we are trying to develop new comprehensive dredge and disposal regs. So we have an opportunity to take from the Boston Harbor Project what was good and what worked and move it forward.

There are a couple of fundamental challenges that we are up against, but before I address those I want to touch for a second on some other things. First very briefly is the permitting side. On the regulator side we were looking at an innovative proposal from the Corps and Massport. We had no guidance at hand, we had no formal regulations and we had no experience. We, being "pinheaded bureaucrats," immediately took a very conservative regulatory approach and felt comforted by the prospect of issuing prescriptive regulations. It would be this high and this wide, etc. The Corps and Massport had more experience than we did in other places and they had more information, but they were against similar kinds of challenges and we were not able to give them information targets that they had to hit in order to convince us of a certain point. That led initially to a lot of wrangling. We did not know what was going on so we were trying to insist on building it big, building it deep, and being very conservative. The proponents were looking for more flexible performance-based standards, so we ended up in a pretty good place, with many compromises, some of which were more acceptable to some people and less acceptable to others. But we ended up in a pretty good place with the TAC, a fairly flexible approach, and it is really that flexibility that I want to think about here as we build new regulations. The one thing that is crystal clear to us as a result of Boston Harbor is that the TAC and the maximum flexibility

approach had to be there to make the project work. In the absence of definitive science and a definitive regulatory approach, you have to have the most flexibility possible to learn as you go along and to get things done.

On the other side, though, at some point there needs to be an underpinning of prescriptive regulations. From the larger point of view you have to have those regulations to get the public to buy into the process. If you go forward to the public at first by saying we want to develop a very flexible process so the applicant has as much latitude as possible to make a project work, then people flip out. To them that is saying it is okay for the applicants to destroy things and behave irresponsibly. For Boston Harbor the compromise ended up being essentially water quality standards plus a standards-based approach operating in the context of a TAC, under the oversight of an Independent Observer.

But now you have got to spin that into a more practical real-world standard. The TAC was comprised of the best and the brightest. We had phenomenal contractors, we had MIT professors, we had folks from the Corps, we had folks from everywhere sitting around the table once every two weeks for a long time. That is a major confluence of intellectual firepower for a major project. For the smaller ports moving forward, and if you think about regulations as an opportunity to take things that are known and try to standardize them so anybody can use them any time, you are not going to be able to get all these people sitting around a table twice a week to make decisions and move forward. So how do we build regulations that strike the appropriate balance between flexibility and prescriptive standards, and write them up and go forward?

There is a lot that goes into that. MADEP as a regulatory agency is chronically understaffed and under funded. We as state agencies are often behind the curve in terms of state-of-the-art information and technology. Whatever is developed needs to be built so that the lowest common denominator regulators can apply it effectively so the public can believe it, but it also has to have that overall flexibility that allows things to change and things to happen in a way that does not tie peoples' hands. So the question I would like to throw out is how to provide both proponents and regulators the flexibility needed to respond cooperatively to

issues that arise across the course of the project?

COMMENT: Communication is probably the number one issue, in that people have to talk to each other rather than just among themselves. You go into a project originally, you may not have had any idea that Massport was under the gun in terms of losing port use, potential shippers leaving etc. They, at the same time, may not have known the issues you were working on, what you were limited to by law. By talking to each other you could figure out what is driving their situation and they can learn from you what bounds the solution has to be within. By doing that you begin to start knowing where the other side is coming from and you can know why they are requesting certain things.

RESPONSE: I agree with you and I do not. It is almost too warm and fuzzy for me. We cannot write regulations that prescribe happiness and communication.

COMMENT: I do not think he is saying you should legislate that in the regulation.

COMMENT: The idea of “to make it work you really need to know where the other side is and why they are there” boils down to understanding their problem. And it works both ways: they need to understand your problem. In the end, it gives you ways of trying to seek that common ground.

COMMENT: I think it is an interesting phenomenon as I look back over the life of the project. In some ways early discussions were very adversarial and we tried early on to lay a groundwork that this project really is good for everyone and I think people bought into that. I think over the life of the project we really did get to understand where each other was coming from. It did not solve all our problems, but it did make a big difference.

RESPONSE: I can think of a specific question that may help focus this. Going forward with the new regulations and thinking specifically about Gloucester, one of the questions we want to address is how do we determine what the maximum permissible upper level of contaminants suitable for CAD cell disposal would be? We talked to the

Federal agencies and the Federal response is Resource Conservation and Recovery Act (RCRA) and also known as Superfund. It is a RCRA standard and this limits the level of contamination at the high end. The city, as they try to develop public support for this approach of having the state regulations determine permissible upper levels of contaminants, and CZM is supporting that. RCRA's numbers are scary and seem arbitrary. Should there be numerical thresholds? What sort of flexibility should you build?

COMMENT: There are so many other things at play. You have to look at the bigger picture. For Boston Harbor you were taking material that was sitting on the surface and you were putting it in a cell in virtually the same location. So even if the cap completely failed, or there was not a cap, you were probably still better off than you had been because at least you had buried a lot of it and sequestered it. You really have to look at the context; a standard needs to take into account the whole environment.

COMMENT: Something we have talked about a lot was using a more risk-based approach and that does not necessarily mean risk-based for marine organisms, but risk-based for the whole project.

COMMENT: Another thing that comes to mind—although I do not know how you would write it into your regulations—is to capture what you have done with this Independent Observer. Somehow you put into the regulations a requirement to have a study group up front.

COMMENT: If you put that in the regulations and required it, on a smaller project would you be able to get people to come and contribute? Usually the people who come have a strong ulterior motive, usually of stopping the project. As a proponent, I am not sure I would want that.

COMMENT: If you do not have the opponents there at the beginning you would not have been able to get much done.

RESPONSE: I do not think you can prescribe this process. You can say you need an advisory

committee and build on that.

COMMENT: Sometimes a lot of the regulations do not consider magnitude, which translates to risk, very well. They try to be prescriptive and one-size-fits all. And it does not work. The testing regulations might be a good example of that. It does not matter the size of your project; you need \$100,000 worth of testing.

COMMENT: One approach for smaller projects is outreach. I do not know if there is a vehicle, if you could get something on the local public stations or something that could describe this process, but that level of outreach and communication might help a lot down the road for some of these smaller communities.

RESPONSE: We actually have a requirement in our permit to do something like this once the project is completed, and it is not completed even though we talk as if it is. Some sort of release, letting people know it is available and doing something more geared to the general public in association with that would be a way to accomplish this. I agree it needs to come from the agencies, and I think that would help in future projects that may be using similar technology. Just to be able to see pictures of what these things look like, it is hard to envision.

COMMENT: What about at the Museum of Science in Boston? What about at the New England Aquarium? I mean the Big Dig, I drive by it every day and I like to see the pictures in the paper that show all that stuff underneath. That gives you a better feel for what is going on.

RESPONSE: We did send a press release out to the media, but we have had a hard time generating interest. We tried to get a lot more press as the project was underway. Anything that was going well we tried to get the press in on, but they were not interested because it was not controversial. There was not interest in that.

COMMENT: Then you have to go to different media.

COMMENT: But a video is a good idea, on public access television. And the time to start thinking about that is probably not when the project is done. Having gone through that process myself I can tell you that it is a long process and to do it right takes time. You need to script it out, storyboard it out, etc.

COMMENT: I think that this project on the whole worked well, it went forward and it is essentially done. However my guess is that there is still a huge population of people out there that did not pay any attention to the project, that still think dredging is bad, end of story. I think it would be an interesting thing to have it at the Museum of Science (Boston, MA) where at least you get people who are interested in that kind of thing and there is a lot of science that goes with it. I think there are a lot of people who do not pay any attention, but still have a perception that this was a bad thing but they did not bother to get involved.

COMMENT: Another project will be to dredge Gloucester, MA, and they are going to have a heck of a time with the fishermen there. If they can hear the story in Boston, maybe it will help.

COMMENT: I know what the regulations are. One of the things that has not been discussed is how rigid the monitoring requirements for those water quality certificates were in terms of what you got back. There are some real downsides right now to the way the system is structured. If you are going to spend some money on monitoring, then can you get the data to be useful to the project and useful to your understanding of the system in the larger sense? It seems to me that is what you really want. How much money did you spend on all this?

COMMENT: Roughly \$200,000 over the project and I do not know if that is the real cost but that was what was paid for monitoring.

COMMENT: Just to add to that, one of the key parts of the Boston Harbor Project was that we conducted the monitoring during Phase I and we followed the exact letter of the water quality certificate. We had a current meter deployed to verify that the reference sample was in fact upstream. We

were out there for 12 hours following every disposal event, sampling every half-hour. We were really all over the harbor and what was great about this project was that at the end of Phase I, which I think was five days of sampling, we were able to report everything to the Technical Advisory Committee and Steve was able to make recommendations. Those recommendations were considered and there were changes made to reduce the time-frame for the monitoring and to eliminate the current meter. So that flexibility was in place for this project.

COMMENT: At the same time we added other things, things we realized were not being monitored.

QUESTION: Deerin, I have a question for you. Do you think that the permit condition we had purely stemmed out of the regulations you were working within or was it part of what evolved out of the process? Because when we entered the process I think there was a lot of concern about water quality impacts and the proponents really forced you to stick to your regulations and stick to your real key concerns so we were not monitoring everything under the sun. I think that if the same project happened again, we would take what we learned and say we did not need to spend a fraction of that much on the water quality monitoring, let us just do a couple days of checks and spot checks here and there. Let us focus on D and E instead of A, B and C. I guess I view that as part of the process instead of necessarily needing to change the regulations, but I do not know if I am off base on that?

COMMENT: That is a really important point because any monitoring plan that is worth its salt has a feedback loop for the data you are gathering, the questions you are asking, and it is flexible to adjust to that so you stay in tune with the questions and issues.

RESPONSE: We really did try to focus the permit on performance standards so there were some feedback loops. That was our emphasis rather than strict "this is exactly what you will do." Rather than how, we tried to give flexibility to the contractor and the proponent though performance standards,

but maybe there could have been more feedback loops.

COMMENT: I cannot even imagine having to do that water quality monitoring program for all of Phase II. I cannot imagine how much less we would have learned. If that had not been scaled back we would not have been able to find the money to do some other things and address some questions that had come up from some of the TAC members. They had a lot of concerns that turned out to be very valid.

COMMENT: The unspoken piece of this, and I have to be as politic as I can because it relates to the way a sister agency is managed; the regulatory agency is understaffed and overworked. The interest is in regulations that can be regionalized to non-specialists. So you have got a regulator that deals with wetlands, waterways and dredging rights. In thinking about all this and talking about developing an adaptive management, all of this is wonderful, but we are really talking about the imposition of hard-core bureaucratic reality on a number of good ideas. How do you develop all this? What are your monitoring techniques? Think of that in the context of the desire of management to create a permit structure where someone in the northeast regional office can get a field report from an inspector or Independent Observer, run down the list, look at the data they have just been given and make sure that week's operation met the permit conditions. That is really the thing to me that makes this extremely difficult. And how can you develop information for a non-specialist in a cubicle, absent the benefit of a TAC?

COMMENT: I think that is a good model of Massachusetts. You have got regulators that are understaffed and overworked. As a comparison you go to a site that has groundwater contamination and the prescription is just put in this many wells, sample for this many parameters and regardless of cost it is just easier for the regulator to check it off. Whereas now the system has gone to a series of licensed site professionals who are chartered by the regulatory agency and are empowered to make site specific decisions and utilize the flexibility in the regulations. How you carry the regulations out is

up to a specific person who can consider the site-specific data.

QUESTION: Can I change back and ask a question we discussed in the beginning? We talked about lessons learned and what we would have liked to do next if we had more money. And I am thinking more of the scientific perspective, etc. From the perspective of management, if you had a million dollars to spend, what would you do? Where would you go from here?

RESPONSE: I have been thinking about that same thing. We should focus a little. Where would you put your money? In research? In policy development? In assessment? Or in monitoring? Do you put it into physical issues, chemical issues, and biological issues, into information transfer? What is the most pressing need you have to move this project forward for the state?

COMMENT: I take the money and put it into monitoring. I care what is happening down there and whether or not it is working. However you want to define "working": "it is safe", etc. Because I am at the interface with the city's interest in dredging and on the other hand heavy duty TAC Boston Harbor concerns. My interest is much more in facilitating the project that happens out there. Get the work done out there. What is the scientific information that is necessary to understand at the most appropriate level? What is the minimum and the right information that we need to know?

COMMENT: My interest is Boston Harbor and, to me, one of the most pressing questions that came up today is do you need to cap? We always talked about leaving one cell uncapped as a study cell and that is what we have right now. We have one cell that has not been capped and we have cells that have been capped. It is a perfect environment to actually be studying that question, and I leave it up to the researchers to figure out exactly how you structure a project like that. To me, that is a pressing question that no one really knows the answer to. If we had a more comprehensive body of research and data maybe we would be able to get beyond the public perception that without a cap the

project is unacceptable no matter the circumstances. We thought the data was out there but obviously it was not because we did not convince people. I believe there should be some sort of independent study that focuses on that issue in the field. Laboratory work is valuable, but there are so many other factors. So if I had the additional money that is where I would put it.

COMMENT: I think the public would probably appreciate more observational data than experimental data, because that is what they can relate to.

COMMENT: Are you using all the contaminated sediments or just those involved in navigational dredging? If you are leaving some of the sediments on the sea floor, then those are going to move over the cap and defeat the purpose.

COMMENT: That leads into another question. Would you consider remedial dredging before such time that you are able to choke off your upstream point sources and affect public policy in such a way that you are no longer getting those inputs?

COMMENT: This is a big issue for port authorities. They are getting saddled with much of the burden for the dredging, but were not causing the contamination. As the costs continue to rise and as federal regulations continue to put more of the burden on the local sponsor, it becomes a more and more pressing issue. None of us has figured out how to do it.

COMMENT: An MIT master's student that just finished up this summer looked at using decision analysis to ask the question of whether you should cap or not and we asked him to expand the study to the long term and see whether or not you should go ahead with remedial cleanup and how that would affect the cost. It was not cost-effective to cap, but the difference between capping and not capping when you were using deep cells with sufficient consolidation times was very minimal. The decision would be one you would make on the basis of some other reason to cap, *e.g.*, if you felt you were going to get more support, or some other benefit outside of just the dollar cost of the environmental benefits in the bay. We then asked him to look at

the long term and whether or not if you cleaned up the rest of the harbor, how would this play out? Down the road, you would probably gain by have less dredging cost, but initially, of course, it would cost you more.

COMMENT: And it depends on the other sources.

COMMENT: That was the crux of our argument of why we did not need to cap. All other things aside, no matter what kind of interactions are going on, the reality is that you have a lot of this material down there and it is basically self-capping so what we put in the cell will become capped over the years and that is also an important piece. We did not win that argument, so I am thinking we need a scientific study about the actual impacts, maybe done independently from the proponents.

COMMENT: I think the cap was originally designed to prevent resuspension. As time went on that became less of an issue. But by that time we had already finished the cap. The initial reason for the cap was for resuspension.

COMMENT: I think the “to cap or not to cap” issue is out there and I think we need a lot more work on it. I have my personal biases on that. The other question was where do we put our funds and I think there are a lot of questions out there—physical, chemical and biological—that I think are site specific.

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